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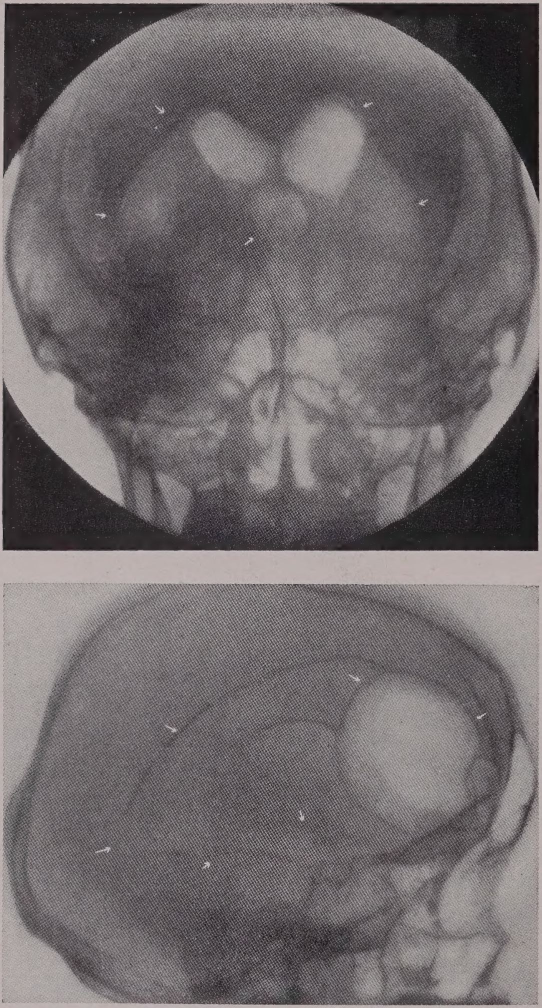

Luckett's original skiagrams, taken by W. H. Stewart, of traumatic aerocoele. So far as is known this was the first demonstration of the ventricles filled with air. (Reproduced from *Surgery Gynaecology and Obstetrics,* 1913, XVII, 238-9, by permission.)

Frontispiece.

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MONOGRAPHS FROM THE WALTER AND ELIZA HALL INSTITUTE OF RESEARCH IN PATHOLOGY AND MEDICINE - MELBOURNE - - - - - - NUMBER TWO

Encephalography

By

E. Graeme Robertson

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Foreword

Medical research, like every other form of scientific investigation, is becoming increasingly specialized. It is now impossible for a single author to write with first-hand knowledge of all the parts of any one subject. Fresh advances are all the time opening up fresh fields and new techniques are being developed which require detailed description if they are to be available for use in other laboratories. The increasing complexity and extent of our knowledge is imposing a fresh duty upon scientific workers, that of reviewing critically the new work in the field which they have made their own.

In Institutes of Research where specialized workers tend to be concentrated a medium for publication other than the ordinary scientific journal must be found if much of the results obtained is not to be lost. During years of work many data are accumulated which are unsuited for publication as isolated scientific papers and which require for their adequate presentation a more detailed review of current knowledge of the subject than could find space in a scientific journal; nor could such papers be included in most collections of review articles. To meet these needs the monograph is an admirable medium, the more so since it allows the author to put forward speculative views which may stimulate much new work. The monograph is also a very suitable form for the description of new techniques allowing space for those details which are essential if the method is to be used by workers who have not the opportunity of seeing a practical demonstration. Furthermore, if many illustrations are necessary, these can only be provided if publication is in book or monograph form. For these reasons the Board of the Walter and Eliza Hall Institute agreed to finance the publication of these monographs and gladly accepted the generous offer of Dr. C. Wallace Ross to act as Editor.

Dr. E. Graeme Robertson, who contributes this second monograph in our new series, is peculiarly fitted for the task he has undertaken. During the whole of his post-graduate career as a neurologist he has been engaged in original research, and latterly, as Neurological Research Fellow at this Institute he has made a special study of the use of encephalography in diagnosis. In the present work he has presented, in full detail, the method as he himself practises it and has described several modifications which are of proven usefulness.

The monograph contains a beautiful series of skiagrams taken after the injection of air into the theca. These are accompanied by photographs indicating the exact posture of the subject and diagrams showing the resulting distribution of air in the ventricles, subarachnoid space or cisterns. Emphasis is thus laid upon the exact posturing of the patient which is essential if the method is to be successfully used. A specially valuable feature of the work has been the careful correlation of these observations with the physical and anatomical factors determining the course of the air.

Dr. Robertson has also recorded the results of a series of encephalograms illustrating the value of the method in diagnosis and the principles of interpretation.

C. H. KELLAWAY

MELBOURNE,
SEPTEMBER, 1941

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Preface

Encephalography has been widely practised, and there may seem little excuse for writing of it twenty years after its introduction. However, a method has been evolved containing a number of new elements which seem worthy of record. Much larger series have been reported by other authors; but some limitation of the number of cases dealt with is an almost necessary consequence of an attempt to carry out personally the whole of the procedures involved in elucidating neurological conditions. The greater part of the monograph deals with the problems of technique and interpretation which have arisen with relation to a number of encephalographies. At the suggestion of the Editor anatomical details, at first omitted, have been added.

A number of problems have been left unsolved and, indeed, some further information is still resulting from almost every case investigated. In spite of this, it has been decided to publish what has so far been done, lest in the present state of world affairs, it should never see the light of day. In fact, most of the work now described was carried out more than a year ago. The technique has been tried by workers in other clinics in Australia, and has been found useful in their hands.

In the circumstances it has not seemed desirable to undertake any exhaustive review of the literature. Had this been attempted, it is improbable that access could have been obtained in Australia to all the relevant papers at the present time. Moreover, an admirable survey is to be found in Davidoff and Dyke's book, *The Normal Encephalogram.* Some justification for this summary dismissal of what is usually regarded as an obligation may be found in the fact that the procedure to be described has resulted from a fresh attack upon the matter, unprompted by any special study of foregoing work. Most of the papers to which reference is made were studied after the work was done.

An assessment of the value of encephalography may have some use at a time when it is to some extent being replaced by electro-encephalography. Although consideration shows that it may fail to reveal definite abnormality, it is felt that the method is still of considerable value in neurological diagnosis. However, it must be admitted that a full study destroys earlier conceptions of its usefulness. One insuperable difficulty rests upon the fact that it shows no difference between anatomical variation and minimal pathological change.

The existence of the book in this form is due to the encouragement of Dr. C. Wallace Ross. Any merits of lucidity which it possesses are due to his editorship. The beauty of its reproduction is due entirely to his unusual technical knowledge.

It gives me pleasure to acknowledge my gratitude to my medical and surgical colleagues on the staff of the Royal Melbourne Hospital, who have allowed me to investigate patients under their care. To Dr. A. E. Coates, whose surgical dexterity and unfailing energy have provided the solution of many neurological problems, I am especially grateful. Mr. Hugh Trumble was responsible for the operation in four of the cases, and Mr. Frank Morgan has allowed me to record details of one, J.S.

I have to acknowledge a deep debt of gratitude to Dr. Barbara Wood. Her efficient direction of a very busy Radiological Department has made possible the deviation of staff and apparatus for this work. I cannot overestimate her co-operation and encouragement. I have also to thank the technicians of the department, and especially Mr. Hayes-Piddlesden, for the patient help they have given in the development of the technique. Most of the films illustrated were taken in the Radiological Department of the Royal Melbourne Hospital. Some were taken at the Austin Hospital for Chronic and Incurable Diseases, and by Dr. J. O'Sullivan and Dr. K. H. Hallam. Dr. R. J. Wright-Smith, Pathologist to the Royal Melbourne Hospital, has been good enough to make available the pathological material for my study, and the discussion of problems with him has been most fruitful. Miss Helen Wischusen has been responsible for the excellent photographs and the preparation of neurological material for microscopy. Mr. L. J. K. Preston, of the Department of Anatomy, Melbourne University, made the celloidin cast of the ventricles, depicted in figure 46a. Professor Sydney Sunderland was kind enough to criticize some of the anatomical descriptions.

I am grateful to Dr. Charles Kellaway, F.R.S., F.R.C.P., for providing pathological and photographic facilities in the Walter and Eliza Hall Institute, and for the kindly and unobtrusive assistance which he has always given. During the time of writing the monograph I was receiving a grant from the National Health and Medical Research Council.

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Contents

PAGE

CHAPTER I

Introductory 1

CHAPTER II

Technique 4
Uses and Contra-indications—Anaesthesia—Apparatus and Usual Procedure—Lateral Skiagrams During Filling—Cisternal Injection —The Posterior Fossa—The Subarachnoid Space

CHAPTER III

Technical Results 35
Efficiency of Filling—Reaction—Therapeutic Effect—Mortality

CHAPTER IV

Routes taken by the Air 37
Anatomical Considerations—Distribution of the Air—Effect of Alteration of Posture—Failure of Ventricular Filling

CHAPTER V

The Fourth Ventricle 45
Anatomy—Appearances in Skiagrams—Measurements—Illustrative Cases

CHAPTER VI

The Aqueduct of Sylvius 54
Anatomy—Appearances in Skiagrams

CHAPTER VII

The Third Ventricle 56
Radiological Anatomy—Illustrative Cases—Anatomical Variations

CHAPTER VIII

The Lateral Ventricles 60
Anterior Horn and Body—The Trigone—Occipital Horns—Temporal Horns—Choroid Plexuses—Relation to Lobes and Dural Partitions —Failure to fill one Ventricle—Deformation by Neoplasm—Neoplasms without Distortion—Post-traumatic Conditions—Size of the Ventricles—Epilepsy—Degenerative, Atrophic and Aplastic Lesions—Typical Cases—Causes Taking Effect in Adult Life— —Vascular Causes—Inflammatory Causes

CHAPTER IX

Air in Extraventricular Positions 93
The Subarachnoid Space—Cerebral Sulci—Filling of Selected Spaces —The Subdural Space—Epidural Injection

CHAPTER X

The Value of Encephalography 102

References 105

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. . . . no other than a moving row
Of magic shadow shapes that come and go.

Chapter I

INTRODUCTORY

Visualization of the cerebral ventricles by radiography was first reported in 1913 by W. H. Luckett, of New York City. The discovery was accidental. Skiagrams taken twenty days after a patient had sustained a fracture of the skull are reproduced in his original papers and clearly show the outlines of the lateral and third ventricles. In view of their historical interest the original illustrations of Luckett's paper are here reproduced as a frontispiece. Operative and post-mortem studies allowed Luckett to reconstruct the series of events which followed the injury:

> It has already been noted that the skull was exceedingly thin, so that when the blow was received over the right orbit there was a buckling upwards of the orbital plate, which fractured and injured the base of the brain just beneath the right anterior horn. A process of progressive softening took place around this point, and when he sneezed the air went up through the frontal sinus, that portion of it that surrounds the inner surface of the orbit, and forced its way through the orbital fracture and through the overlying adherent softened lacerated area of the base of the frontal lobe into the anterior horn of the right lateral ventricle. The air passed through the foramen of Monro into the third ventricle, through the corresponding foramen of Monro into the left lateral ventricle (antero-posterior pictures show both lateral ventricles distended with air), and through the third ventricle posteriorly into the iter a tertio ad quartum ventriculum (aqueduct of Sylvius), into the fourth ventricle, and at the posterior angle of the roof out through the foramen of Magendie into the cisterna cerebello medullaris (cisterna magna), where at the occipital operation we saw it bubbling up through the cerebrospinal fluid in the cistern.

The clinical methods of encephalography have their origin in the clear perception and brilliant enterprise of Dandy. In 1918 he wrote:

> For some time I have considered the possibility of filling the cerebral ventricles with a medium that will produce a shadow in the radiogram. If this could be done, an accurate outline of the cerebral ventricles could be photographed with X-rays, and since most neoplasms either directly or indirectly modify the size or shape of the ventricles, we should then possess an early and accurate aid to the localization of intracranial affections. In addition to its radiographic properties, any substance injected into the ventricles must satisfy two very rigid exactions: (1) it must be absolutely non-irritating and non-toxic; and (2) it must be readily absorbed and excreted.
>
> The various solutions and suspensions used in pyelography . . . were injected into the ventricles of dogs, but always with fatal results, owing to the injurious effects on the brain. . . .

> Ventriculography, therefore, seems possible only by the substitution of gas for cerebrospinal fluid. It is largely due to the frequent comment by Doctor Halsted on the remarkable power of intestinal gases "to perforate bone" that my attention was drawn to its practical possibilities in the brain. Striking gas shadows are present in all abdominal and thoracic radiograms. The stomach and intestines are often outlined by the contained air, even more sharply than when filled with bismuth. A small collection of gas in the intestines often obliterates the kidney outlines. A perforation of the intestines may be diagnosed by the shadow of the air that has accumulated under the diaphragm. Gas gangrene may be diagnosed by the air blebs (of B. welchii) in the tissues. Pneumothorax is sharply outlined because the normal lung tissues are eliminated. The paranasal sinuses and mastoid air cells show up in a thick skull by virtue of the air, and pathological conditions of the sinuses are evident because inflammatory or tumour tissue replaces the air. From these and many other normal and pathological clinical demonstrations of the radiographic properties of air it is but a step to the injection of gas into the cerebral ventricles—pneumoventriculography.

In 1919 Dandy wrote a second important paper, in which he introduced a method of visualizing the subarachnoid space, stating that:

> As was shown in a recent publication, one or more of the cerebral ventricles can be sharply outlined in a röntgenogram if the ventricular fluid be withdrawn and replaced by an equal quantity of air. In the course of this work it was soon noted that in many cases some of the air had passed out of the ventricular system and could be seen in filaments on the surface of the brain, that is, in the sulci. . . .
>
> These observations at once gave promise of new possibilities in intracranial diagnostic study. Many lesions of the brain affect part of the subarachnoid space directly or indirectly. . . .
>
> After the injection of air into a cerebral ventricle a certain amount will soon appear on the external surface of the brain if the head is carefully manipulated so that the air is guided to the small aqueduct of Sylvius and the fourth ventricle. But the time of escape of air from the ventricles and of its appearance in the cerebral sulci are variable. . . .
>
> The problem therefore before us was: How can we in every case be sure of obtaining a complete injection of the subarachnoid space? The solution lies in the direct injection of air into the spinal canal. By this method the influence of the ventricular system is entirely eliminated; the air passes directly into the cisterna magna and thence into the ultimate ramifications of the subarachnoid space.
>
> The technique is essentially similar to that described elsewhere for intra-ventricular injection. A small quantity of spinal fluid is withdrawn and an equal amount of air injected into the spinal canal. This process of substitution is repeated until the fluid ceases to appear on aspiration.

As the introduction of gas into the spinal canal outlined the subarachnoid space as well as the cerebral ventricles the procedure was properly termed encephalography by Bingel in 1921. Many subsequent workers have used large quantities of air, but Laruelle (1933) sought to refine the method by using very small amounts of air. As a result of his work, he was able to describe encephalography as an easy and harmless diagnostic procedure, and there can be little doubt that reduction in the amount of air robs the method of most of its hazards, if also on occasion of a little of its diagnostic value. In his original paper, Laruelle lays down some rules:

> At the outset I consider it useful to enunciate certain inflexible rules for the success of the examination, failure to observe which is the commonest cause of failure:
>
> (1) The injection and the radiography should be carried out on the sitting subject. This is of prime importance, seeing that the air, being lighter than the cerebrospinal

fluid, when injected by the lumbar route must ascend the length of the cord and reach the cerebral ventricles, where it must remain in the highest positions.

(2) At the moment of injection the head should be slightly flexed on the spine: if it is too nearly vertical the air passes often into the pericerebral spaces; if too much flexed, it also passes into the pericerebral spaces, or more often comes to lodge under the tentorium cerebelli.

(3) To obtain a picture of the third ventricle, the skiagram should be made immediately after the injection, for after a very short interval the air leaves the third ventricle to pass by the foramina of Monro into the higher-placed lateral ventricles. It is necessary to place the patient in this position for radiography immediately after the injection, and to have all the X-ray equipment ready to operate at once.

(4) Immobilization of the head should be possible in a position which is always the same, the patient being comfortably seated. . . .

He advocates the injection of 2, 3 or 5 c.cm. of air at the rate of 1 c.cm. per second. He states that too slow an injection often leads to the following of false routes. If a postero-anterior view, taken with the head erect, is normal, he considers it unnecessary to take further views. If an air-bubble is not seen in the skull, or if it is abnormal, more air is injected and profile views taken with the head erect. If there is a difference in the filling of the ventricles, the "lateral-transit test" is performed to secure the transference of air to each lateral ventricle in turn. When one wishes to estimate the size of a ventricle, as in hydrocephalus, one can attain this end with a minimal amount of air, not exceeding 10 c.cm. It is sufficient to take films of the head in six different positions, thus demarcating six portions of the outline in turn.

When the ventricles alone are outlined the term lumbar ventriculography might well be applied; nevertheless, it is convenient, and in accordance with convention, to retain the term encephalography to cover the procedures in which the air is introduced into the lumbar subarachnoid space.

The essential point of the method to be described is the observation of the passage of a limited quantity of air from the spinal canal to the highest point to which it can rise. Radiography is used to provide a running commentary upon the progress of filling. The application of anatomical knowledge allows filling of the ventricles alone, or of selected parts of the subarachnoid space. Excellent pictures of the fourth ventricle have been obtained in every case in which these were desired.

Chapter II

TECHNIQUE

Three aspects of the method present themselves for consideration—the recognition of suitable indications, the efficient conduct of the actual procedure, and the interpretation of the appearances found.

Uses and Contra-indications

The procedure has been applied only in cases where a definite clinical diagnosis was impossible and where it was hoped that the patient might gain from the knowledge acquired. It was used chiefly to exclude the presence of a removable lesion, but increasing experience has shown that the method may fail in this, its most important purpose. The failure to gain useful knowledge in many cases tends to reduce the number which will later be subjected to the procedure.

It has been avoided in patients in whom symptoms, signs or lumbar manometry indicated an increased intracranial pressure. In such cases, when an accurate clinical diagnosis was impossible, ventriculography was used. Most authors regard increased intracranial pressure as an absolute contra-indication, yet Gardner and Nichols (1933) have performed complete replacements in thirty-three patients in whom papilloedema was present. In several of their cases the intracranial pressure was extremely high. The only untoward result was respiratory embarrassment in one case of obstructive hydrocephalus, and this was relieved by ventricular puncture. If choking of the optic discs is present, they urge that encephalography should not be performed until all preparations have been made for an immediate craniotomy.

It is believed, however, that the risk of encephalography is increased in the presence of a neoplasm, even when there is no indication of increased intracranial pressure.

H.T., a woman of thirty-five years was known to have had a homonymous hemianopia for five years. She also suffered from momentary attacks in which she felt a sensation "like water at the back of her throat." She denied having suffered from headaches. She showed some mental torpidity, but was able to co-operate quite well during detailed neurological examination. There was no aphasia. She was right-handed. There was a left-sided homonymous hemianopia with sparing of the fixation points. There was no papilloedema. The left corner of the mouth moved less well than the right. The pressure of the cerebrospinal fluid was 120 mm. and jugular compression caused a brisk rise, followed by a satisfactory fall. Skiagrams of the skull were normal. Contrary to the usual practice of avoiding investigation if the diagnosis seemed to be clear on clinical grounds, encephalography was performed to enable the surgeon to plan an accurate approach to the tumour. Five c.cm. of air were slowly introduced. This air accumulated in the cisterna magna and did not reach the ventricles. Five c.cm. of cerebrospinal fluid were slowly evacuated. During this procedure the patient became drowsy, pale and cold, and vomited once. The pulse

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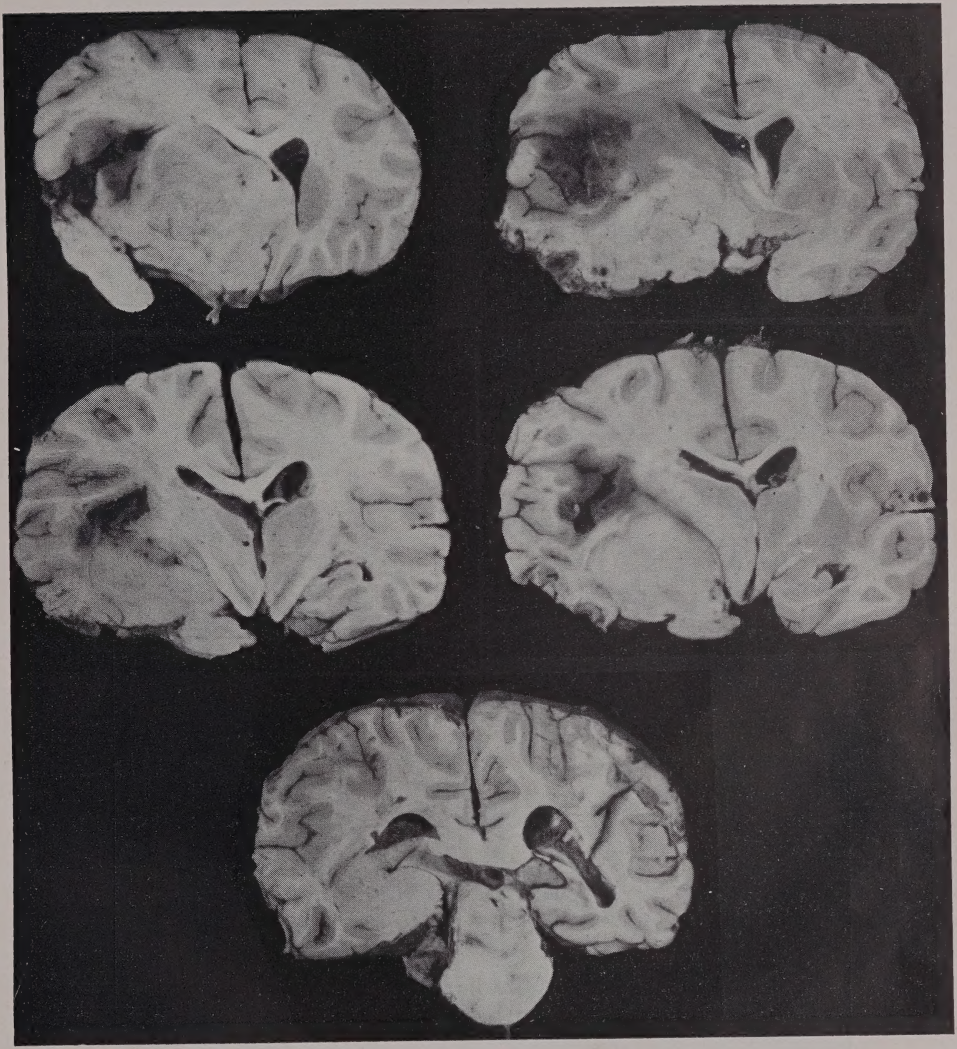

Fig. 1—Coronal sections showing a glioma of the right temporal lobe, with herniation through the incisura tentorii.

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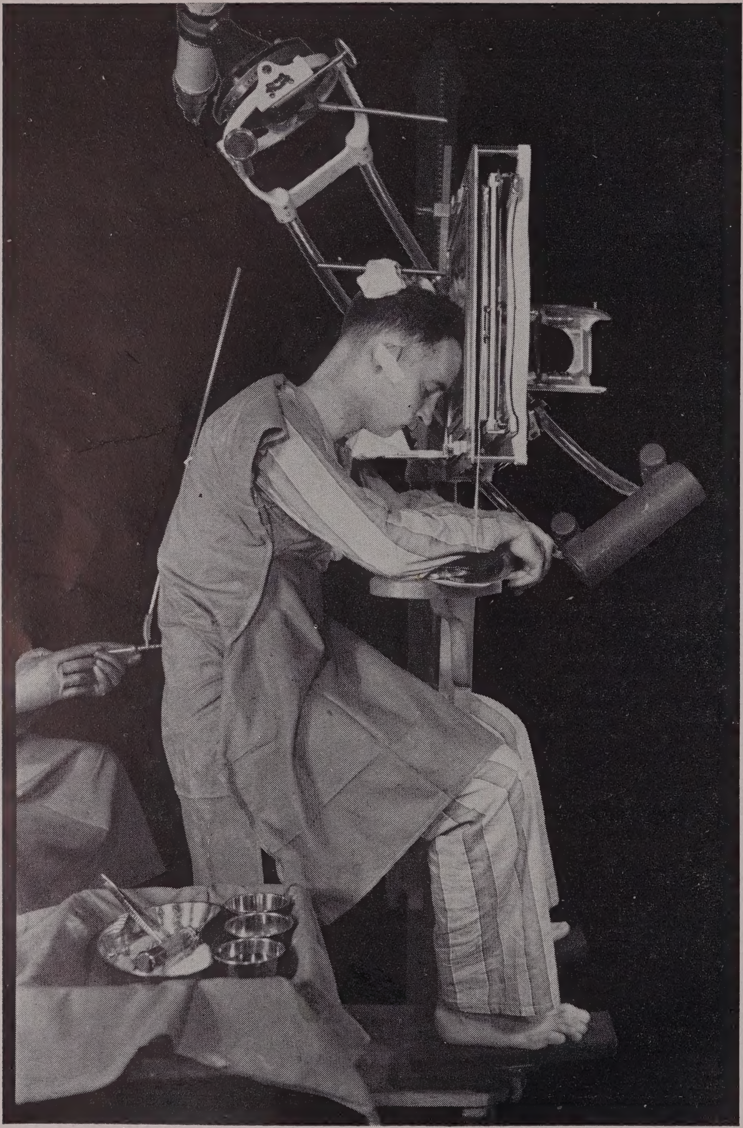

Fig. 2—Patient seated at the Schönander head-table. The head is held by a rubber chin-rest and a special head-piece; the ears are held forward by strapping, to clear the fourth ventricle. Less flexion of the neck is now used.

rate fell to forty-two. The left pupil was noticed to be slightly larger than the right and there was slight ptosis of the left upper eyelid. It was thought probable that herniation of the right uncus through the incisura tentorii had increased during the evacuation of fluid. She was subjected to immediate operation and a glioma was found in the right temporal lobe. She died thirty-six hours after operation, and the tumour was found to occupy the right temporal lobe and the postero-inferior part of the frontal lobe (Fig. 1). It extended downwards through the incisura tentorii and caused gross displacement of the third ventricle, the aqueduct of Sylvius and the upper part of the fourth ventricle. The appearance of the hernia suggested that it had been present for some time, and that it was mainly produced by downward growth of the tumour. A large part of the tumour was white and firm, and proved to be a fibrous astrocytoma; but some parts of greyish-red appearance were much more cellular, resembling a glioblastoma multiforme.

The final result was not altered by encephalography, but the case serves as a warning that the investigation should be avoided unless it is necessary, and that danger does exist when incisural or foraminal herniation is present even in the absence of any symptoms or signs of increased intracranial pressure. Encephalography has been avoided in patients with marked arteriosclerosis, hyperpiesis, and intracranial aneurysms, which conditions figure prominently among the few fatalities reported. If an aneurysm is suspected, it is not likely that this method of investigation would be used; but it is probable that it has been applied without mishap to a number of patients in whom an aneurysm remains unsuspected, even at the end of investigation.

Anaesthesia

Encephalography can usually be carried out under a mild sedative, such as chloral hydrate, with but little discomfort. A sixth or a quarter of a grain of morphine is often given late in the procedure to reduce the headache which usually follows movement of the head. The sequelae are usually slight and the patient is little inconvenienced.

Where complete replacement is to be undertaken basal narcosis, or preferably general anaesthesia is usually employed. Evidence of shock is much less marked where general anaesthesia is used. In the case of children, ether given by the open method has proven especially satisfactory. Since the presence of the mask prevents the assumption of the usual posture, the patient is placed side-on to the vertical head-table so that lateral skiagrams may be taken during filling (Fig. 14). Bands passing about the body are used to maintain the erect posture. Whether or not a general anaesthetic is used, it is most important to keep the patient thoroughly warm.

Apparatus and Usual Procedure

The radiological apparatus used at the Royal Melbourne Hospital is the Schönander head-table made to the design of Lysholm (1931), and incorporating a moving grid. A Siemens tube of fine focus is used, having a capacity of 1·5 kilowatts. The distance between target and film is twenty-eight inches. The procedure can be satisfactorily carried out without this special equipment, wherever vertical and horizontal films can be taken, preferably with the aid of either a Potter-Bucky diaphragm or a Lysholm grid.

An hour after a very light meal the patient is given twenty grains of chloral hydrate. Half-an-hour later he sits on a padded stool (Fig. 2) with his legs on each side of a central standard. The arms lie comfortably on a padded shelf carried by the standard. The feet rest on rubber supports arranged after the manner of organ-pedals. A modernistic steel chair of tubular construction, or the adjustable type as used by stenographers, is an excellent substitute. A broad band attached to the padded shelf may be used to support the back. This is necessary if an anaesthetic is used. The patient is placed so that the forehead rests against the head-table, which for this part of the investigation is in the vertical plane. The chin is supported in a depression in a rubber chin-rest at the lower end of the head-table. In conjunction with this chin-rest a steadying device resting lightly on the vertex keeps the flexed head in the midline of the table with the minimum of discomfort. This device consists of a broad pad of sponge-rubber mounted on a wooden base, which is adapted to the transverse biparietal curve of the head. It is mounted at the upper end of the head-table and can be adjusted in any direction. The height of the head-table is so arranged that the patient's back is slightly flexed, and the head so flexed that a line passing through the lateral canthus of the eye and the external auditory meatus makes an angle of ten to fifteen degrees with the horizontal.

A fine lumbar-puncture needle of Greenfield's pattern is used. It has a three-way tap, and the needle is bevelled on the side opposite to the vertical outlet. During lumbar puncture the bevel is kept vertical so as to separate the vertically-directed dural fibres. It is important to make a definite puncture of the arachnoid in order to avoid the introduction of air into the subdural space. When the point of the needle is within the subarachnoid space its axis is rotated through ninety degrees, so that the bevel is now directed downwards. This tends to prevent blockage of the outflow of fluid by nerve-roots, which might be pressed against a vertically-directed bevel. A glass manometer tube of two-millimetre bore is attached to the vertical outlet. It is of sufficient length to reach to the patient's vertex and is attached to the towel covering his back by a clip. The stylet is removed and the tap turned to allow the cerebrospinal fluid to rise into the manometer. Usually, when the intracranial pressure is normal, the fluid fluctuates at about the level of the base of the skull. The pressure of the cisternal fluid when measured at cisternal or lumbar puncture without loss is found to be slightly in excess of atmospheric pressure. The amount of fluid necessary to fill the manometer reduces the level a little.

The gas employed has, as a routine, been that most readily available—air. The reaction to the procedure being relatively slight, it was felt that little would be gained by using any other gas, especially as other authors had not adduced convincing evidence that other gases were superior. There seems, however, to be some reason in the suggestion that oxygen, as a more readily absorbable gas than nitrogen, might give rise to less reaction. Observations are therefore being made on the point.

TECHNIQUE

In the following pages what might be termed the full normal technique is described. This does not, however, represent a routine to be slavishly followed. Indeed the actual series of procedures varies almost from case to case. For instance, if the lesion is in the cerebral hemispheres one or two films only will be taken with the head erect, whereas if it lies in the posterior fossa these erect films provide most of the obtainable information, and therefore become the main feature of the investigation. Similarly, if the earlier films indicate difficulty in obtaining the desired filling a suitable modification of the procedure can be made.

(1) A syringe is filled with air drawn through a pad of sterile cotton-wool. Five c.cm. is then slowly introduced through the needle. The rate of injection is usually about one c.cm. per minute. A postero-anterior skiagram is immediately taken, without moving the patient's head, the centre ray being inclined upwards at an angle of five degrees (Fig. 3a). While the film is being developed, cerebrospinal fluid is allowed to drip very slowly from the needle until the manometer records approximately the initial pressure.

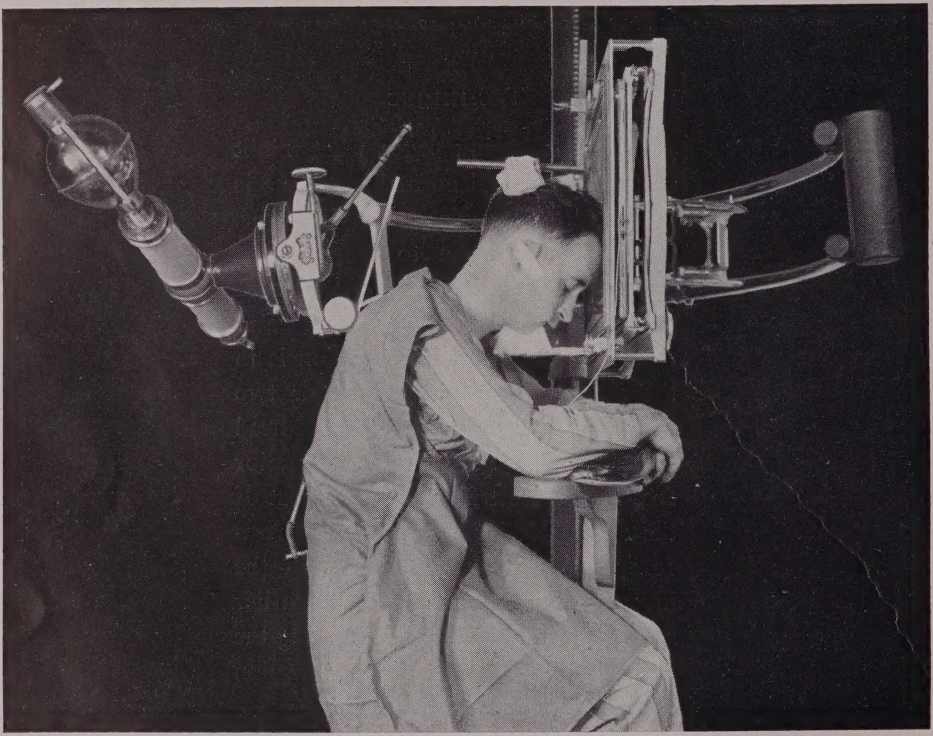

Fig. 3a—The position for the first (postero-anterior) skiagram.

The first picture (Fig. 3b) usually shows air in the fourth ventricle, the aqueduct of Sylvius and the third ventricle. In a small number of patients the air has not entered the ventricle at this stage, but is seen to be collected in the cisterna magna (Fig. 17e).

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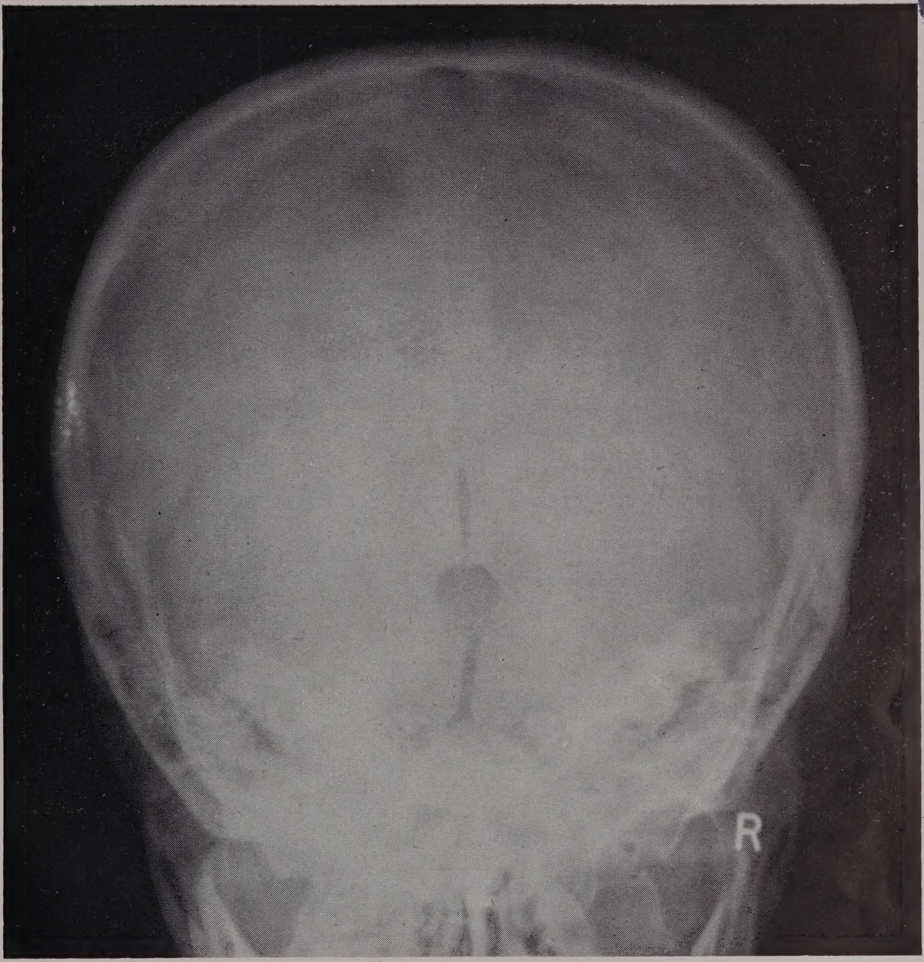

Fig. 3b—Typical postero-anterior skiagram (5 c.cm. of air).

(2) After 10 c.cm. of air have been introduced the patient's head may be placed so that nose and forehead are in contact with the head-table (Fig. 4a),

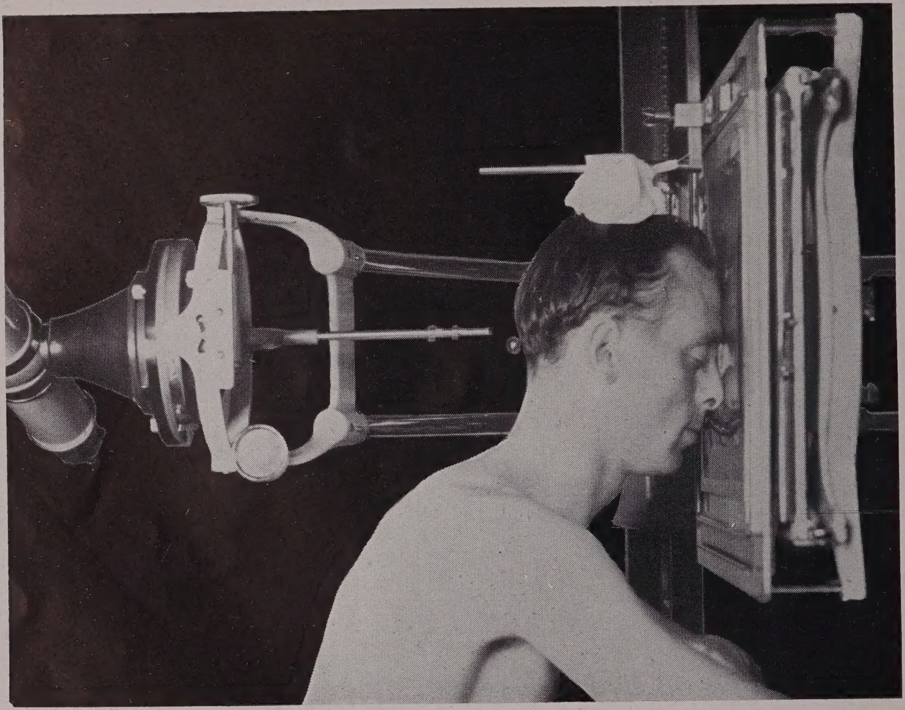

Fig. 4a—Nose-forehead position, to show the fourth ventricle.

and a skiagram taken with the centre-ray horizontal (Fig. 4b). This film is usually taken only if the fourth ventricle is being examined. For reasons

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to be discussed later the assumption of this posture may lead to the passage of air from the cisterna magna, where it had previously been accumulating, into the ventricles. If the ventricles are outlined, the investigation is continued after restoring the head to the original semi-flexed posture. If air has not reached the ventricles modifications of the routine procedure are undertaken.

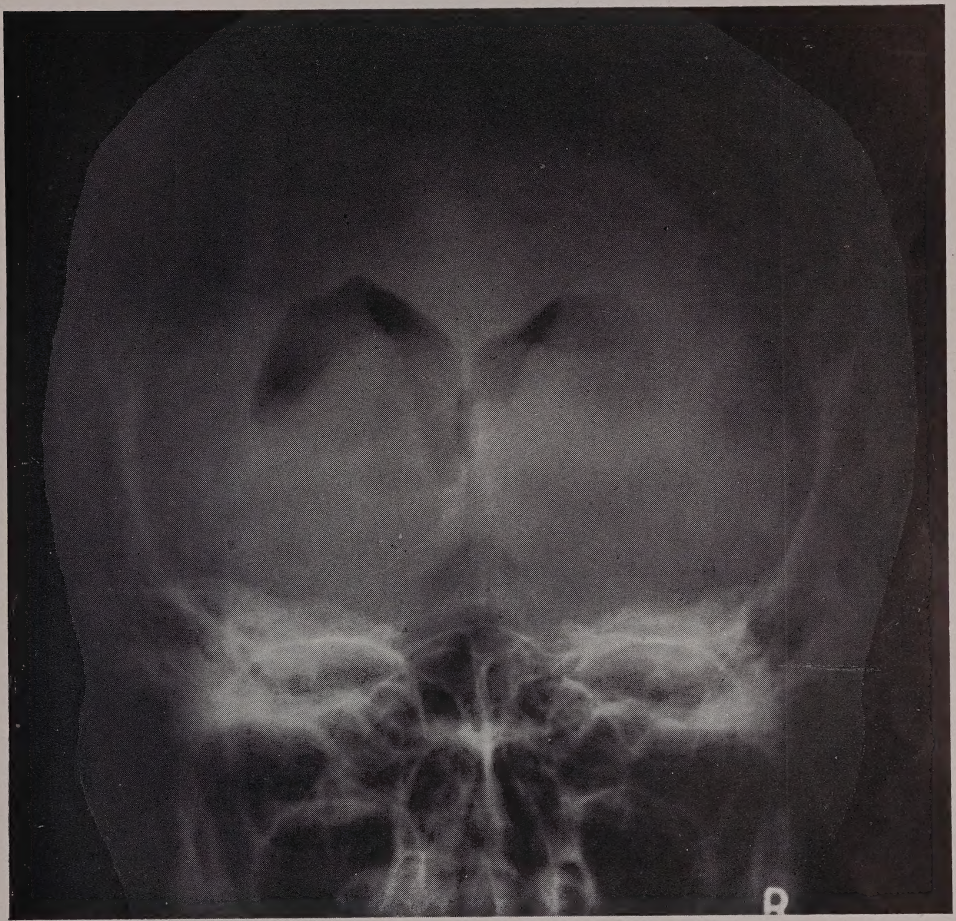

Fig. 4b—Typical skiagram in nose-forehead position (15 c.cm. of air).

(3) During the introduction of a further 5 c.cm. of air the X-ray tube is shifted to take a lateral view of the skull. The film and a Lysholm grid are held against the side of the patient's head at right angles to the head-table (Fig. 5a). The shadows of the cartilages of the ears may obscure the outline of the fourth ventricle; hence it is advantageous to fix the pinnae forward with adhesive tape. This film (Fig. 5b) demonstrates, in lateral view, the fourth ventricle, the aqueduct of Sylvius, the postero-superior part of the third ventricle, the posterior parts of the bodies of the lateral ventricles and the occipital horns (Fig. 5c). The size of the lateral ventricles may be estimated and a judgment made of the amount of air which will suffice to give an adequate ventricular picture. (In a normal subject about 20 c.cm. is usually used). Alternate introduction of air and removal of fluid is continued until a satisfactory filling is seen.

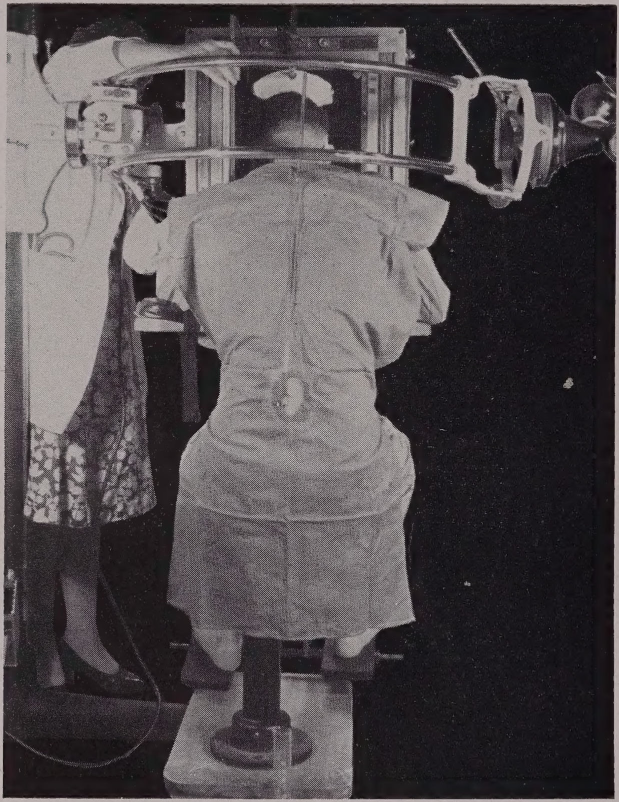

Fig. 5a—Position for the lateral skiagram during filling.

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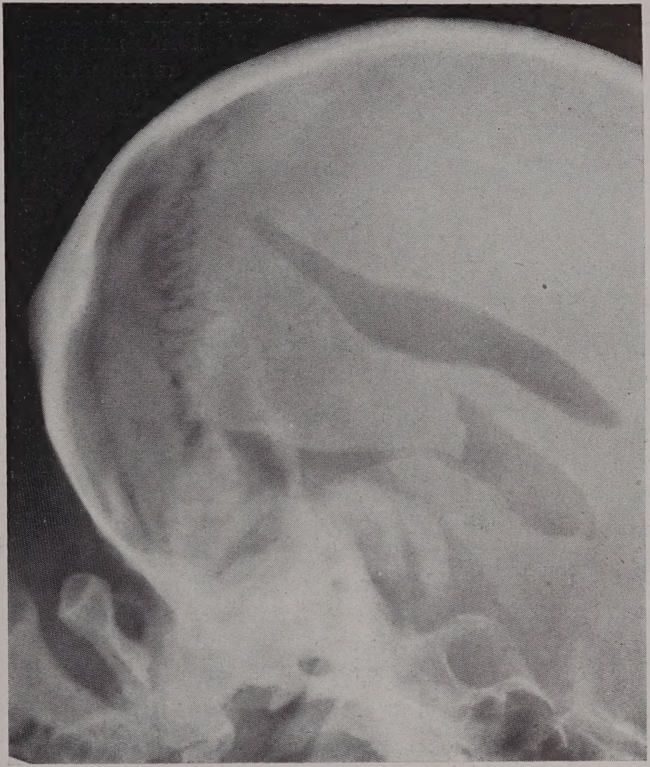
Fig. 5b — Typical lateral skiagram.



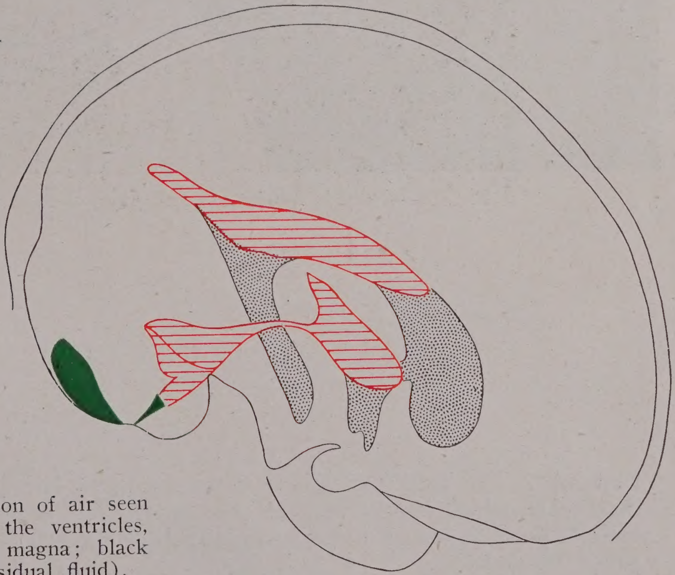


Fig. 5c—The distribution of air seen in figure 5b (red in the ventricles, green in the cisterna magna; black stipple represents residual fluid).

(4) After the last introduction of air the patient's head is very slowly dorsiflexed, in order to bring the posterior part of the cisterna magna to a lower level and so secure the passage of as much air as possible into the ventricles. The head may then be rotated into the lateral position against the head-table, which is still vertical (Fig. 6a). The film, which is now taken without delay, is useful in the examination of the third and fourth ventricles (Figs. 6b and 6c).

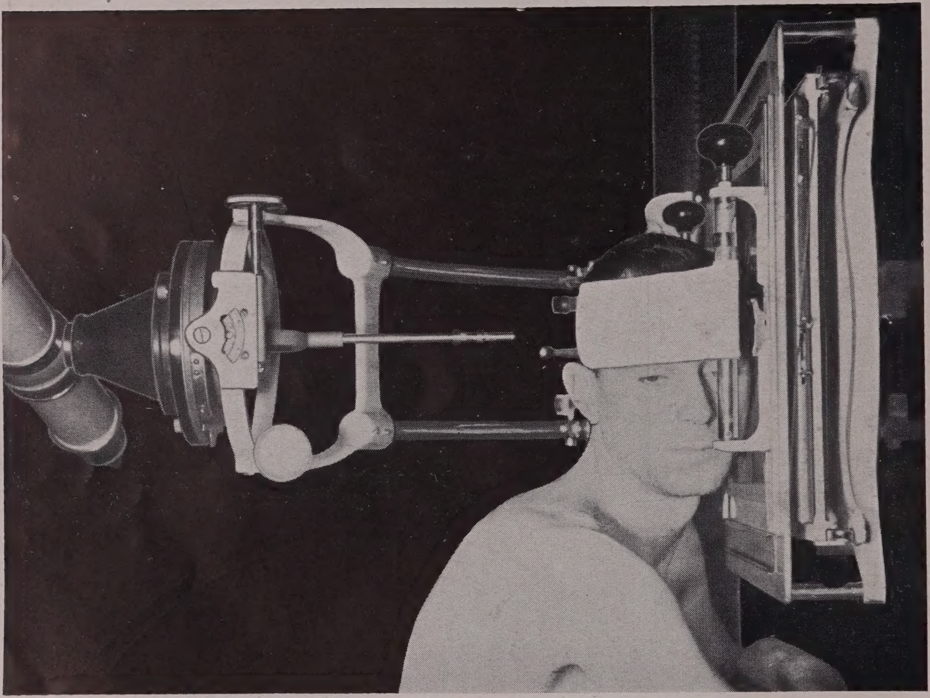


Fig. 6a—Position for lateral skiagram, with head erect.

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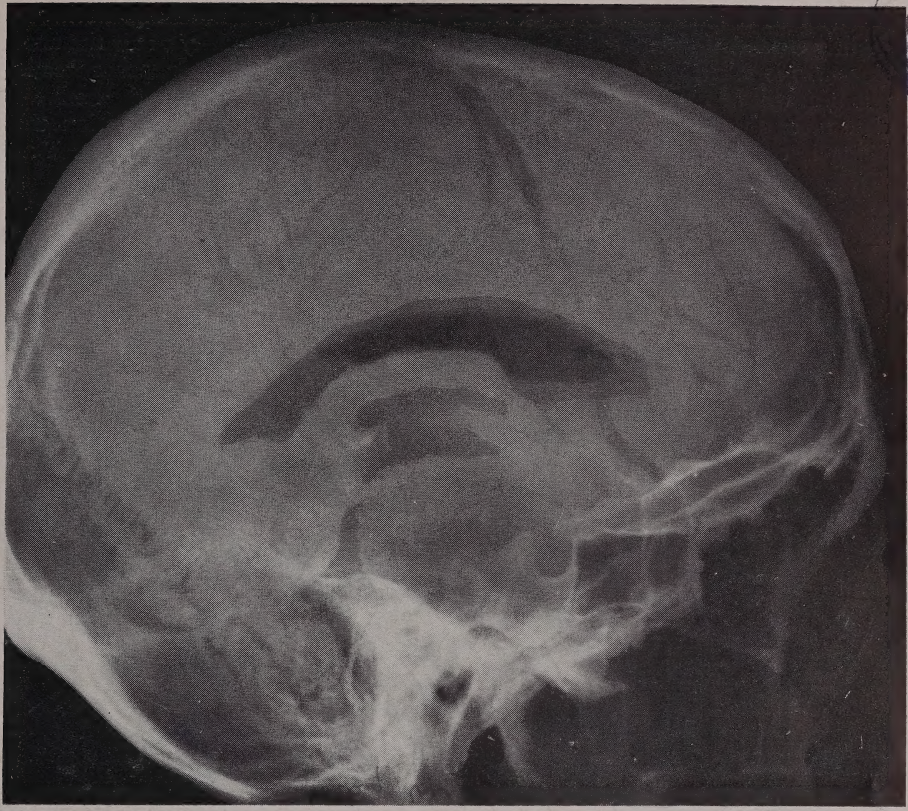

Fig. 6b—Typical lateral skiagram.

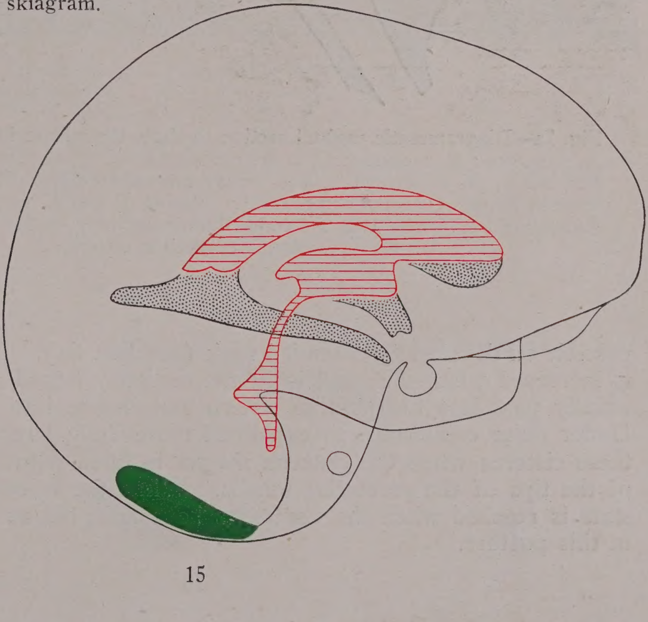

Fig. 6c—The distribution of air in figure 6b (red in the ventricles, solid green in the cisterna magna; black stipple represents residual fluid).

(5) If it is desired to outline the basal cisterns, the head and neck are slightly extended and after the introduction of a further quantity of air the final skiagram is taken with the vertex uppermost (Fig. 7b). The appearances in this film will be made clear by reference to figures 7a and 7c. If the ambient cistern, or the region of the quadrigeminal plate requires investigation the filling is continued with the head erect, or with the head flexed as much as possible on the slightly-extended neck (see Fig. 62). If the rate of injection is increased when the head is in the ordinary flexed posture some air will usually pass into the pontine cistern and thence into the ambient cisterns. Under these conditions, as explained more fully later, the air escapes into these cisterns when the cisterna magna is filled with air down to the level of the tips of the cerebellar tonsils. When the injection is very slow this state is reached when the ventricles have accepted as much air as possible in this posture.

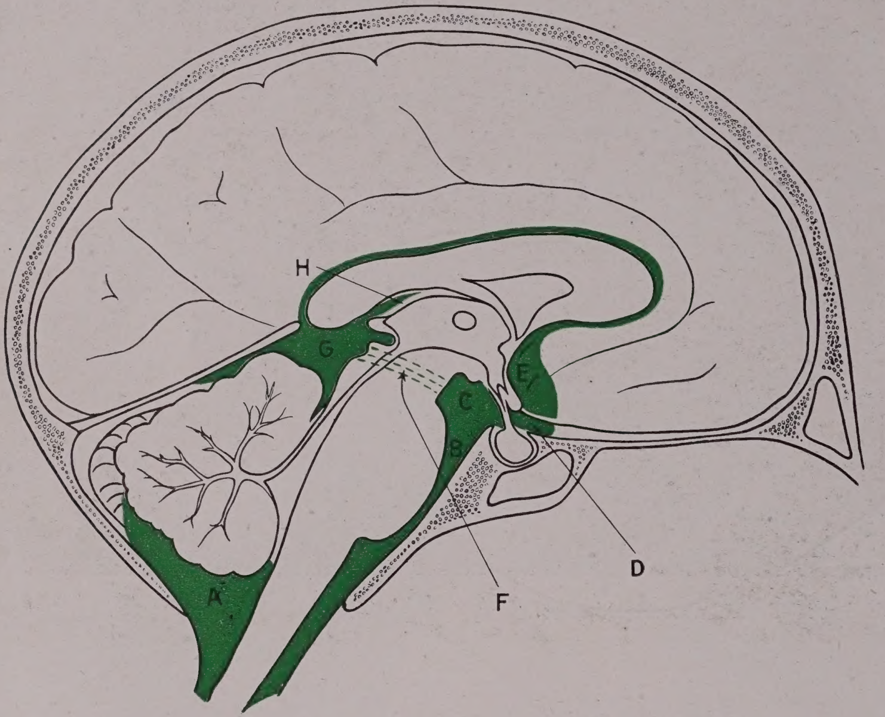

Fig. 7a—Diagrammatic sagittal section to show the subarachnoid cisterns (green). A, c. magna; B, c. pontis; C, c. interpeduncularis; D, c. chiasmatis; E, c. laminae terminalis; F, c. ambiens; G, c. venae magnae cerebri; H, central part of the choroid fissure (usually obliterated). Joining E and G is the c. corporis callosi. Extending backwards over the cerebellum from the c. venae magnae cerebri is the superior cerebellar cistern.

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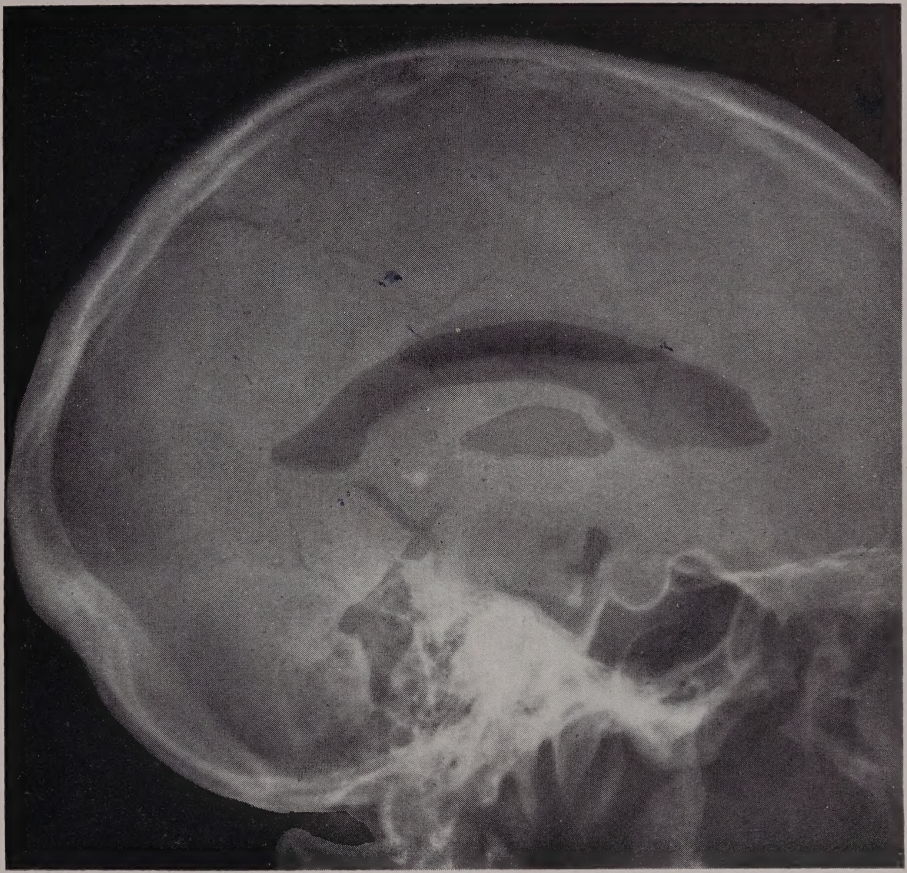

Fig. 7b—Early stage of filling of cisterns. Air is seen in the cisternae magna, pontis, interpeduncularis, and ambiens.

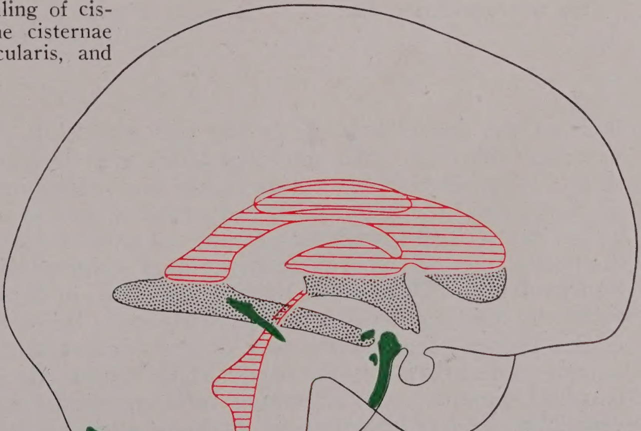

Fig. 7c—The distribution of air in Fig. 7b (red in the ventricles, green in the cisterns; black stipple represents residual fluid).

(6) The needle is removed and the patient assumes the supine posture. The air rises into the anterior parts of the lateral and third ventricles (Fig. 8). In order to obtain a symmetrical distribution in the lateral ventricles the head is now gently rotated from side to side a number of times, while being kept moderately flexed. If the foregoing films show a pronounced disparity between the amounts of air in the two ventricles, this procedure is made especially thorough. An antero-posterior view is taken with the centre ray directed parallel with, but a little cranial to, the line through the outer canthus of the eye and the external auditory meatus, and at right angles to the film (Fig. 8a). The significance of the component parts of the characteristic "butterfly" picture has been described by Torkildsen and Penfield (1933) and by Davidoff and Dyke (1935) and is illustrated in figures 8b, d and 43. Provided the fluid level in the lateral ventricles is below the foramen of Monro in this posture, the anterior part of the third ventricle will contain air. It is seen as a narrow slit-like cavity, at the upper end of which the interventricular foramina may sometimes be seen communicating with the lateral ventricles. If it is important to obtain as much information as possible about this part of the third ventricle a lateral film is taken without disturbing the position of the head (Figs. 8b and 63).

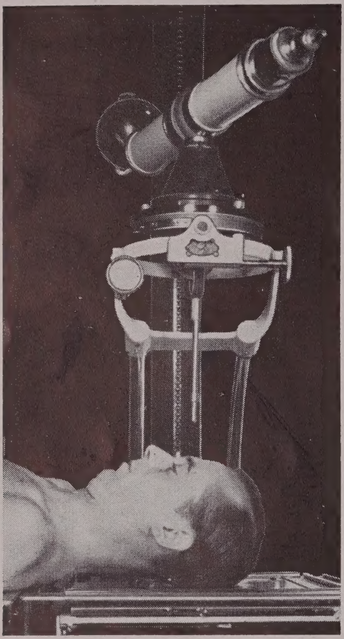

Fig. 8a—Position for the antero-posterior film.

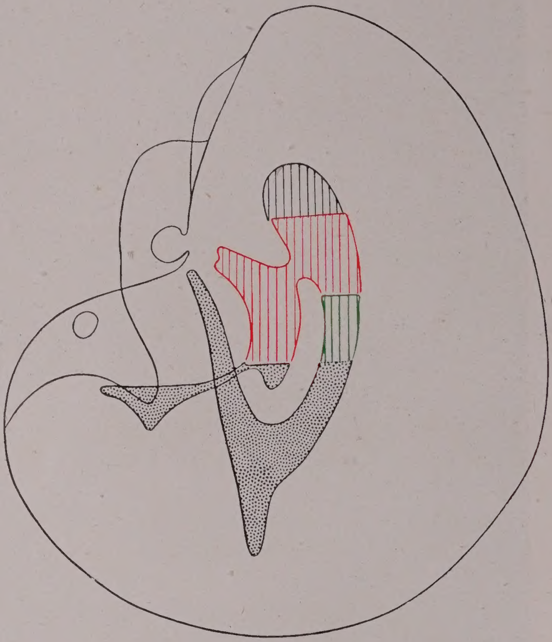

Fig. 8b—The air in the ventricles in this position, as it would be seen if viewed laterally. The code of shading is as in Fig. 8d.

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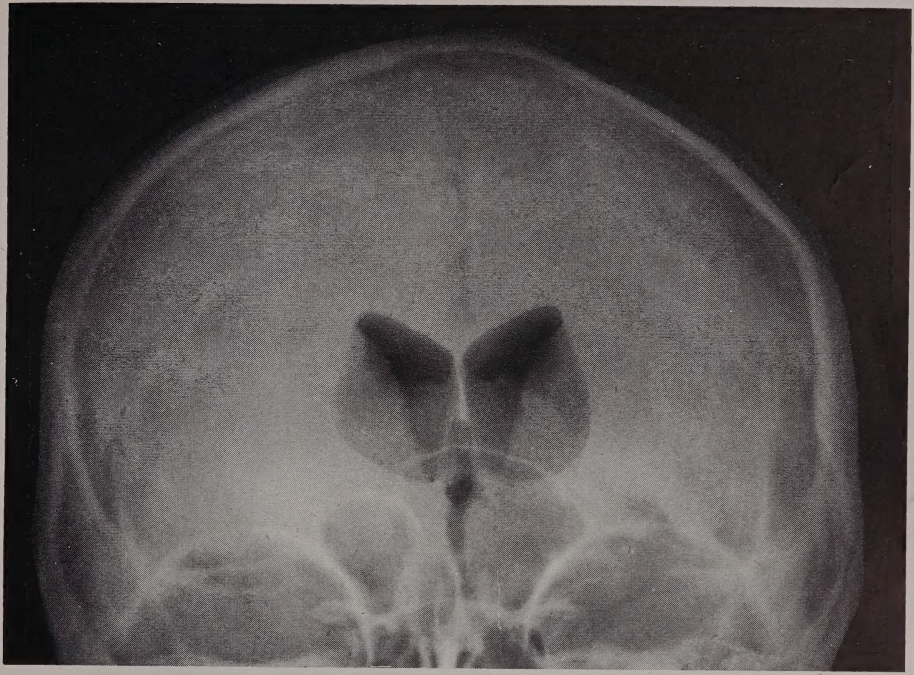

Fig. 8c—Antero-posterior skiagram.

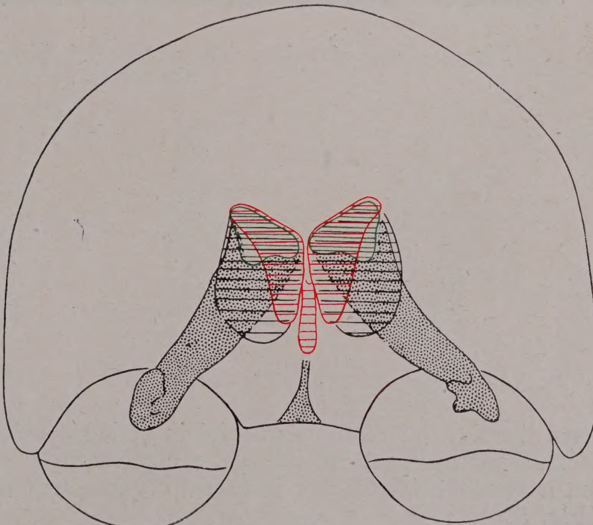

Fig. 8d—The component parts of the air-shadow seen in Fig. 8c (black linear shading, tips of anterior horns; red, third ventricle, posterior part of anterior horns and anterior part of bodies; green, middle part of bodies; black stipple, residual fluid).

(7) A supplementary view of the anterior parts of the lateral ventricles may be obtained by swinging the tube through an angle of thirty degrees towards the vertex, the position of the head and the film being unaltered (Fig. 9a). The centre ray is directed towards the mastoid processes as viewed from the side. This film is useful in giving a view, distorted though it is, of the septum pellucidum, and of the third ventricle. It is not used as a routine but is valuable when there is lateral displacement of the ventricular system (Fig. 53c).

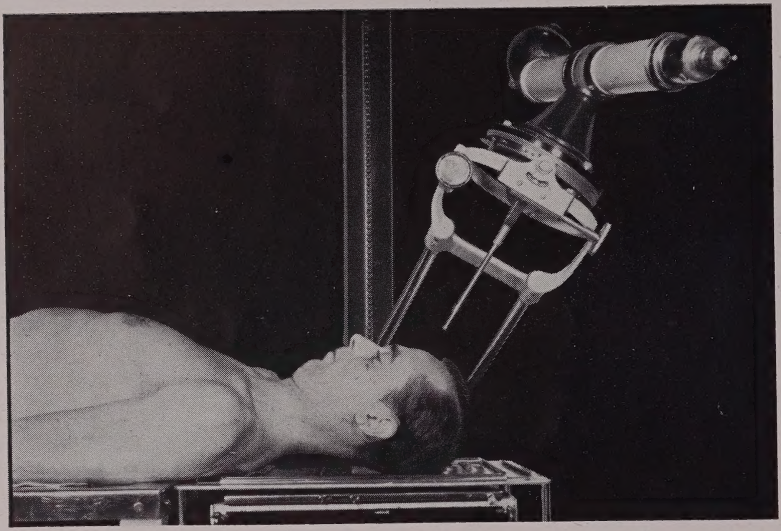

Fig. 9a—Inter-axial view. The centre-ray is inclined at 30° towards the vertex.

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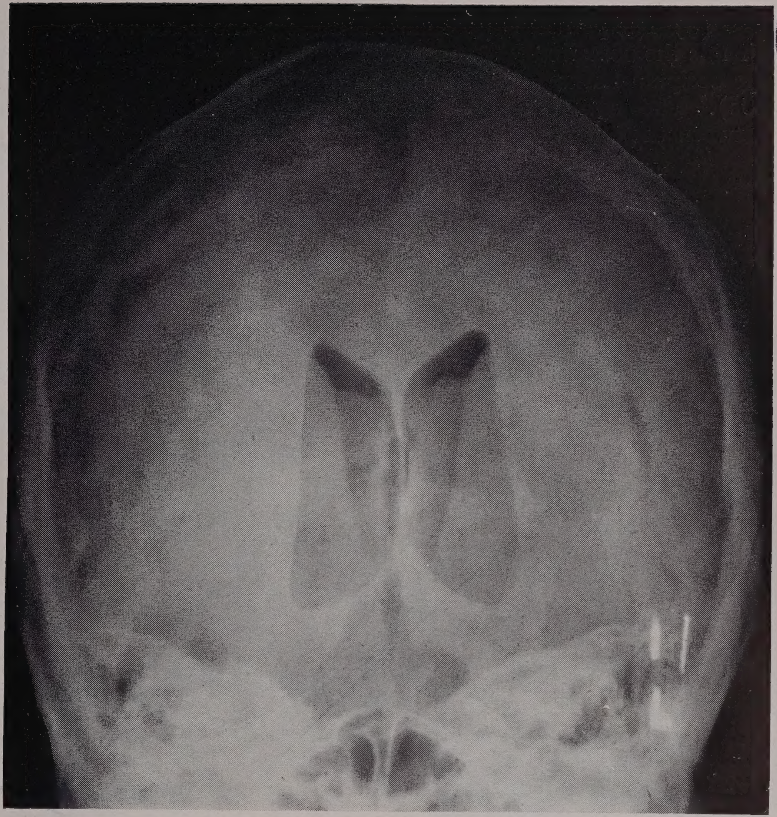

Fig. 9b—
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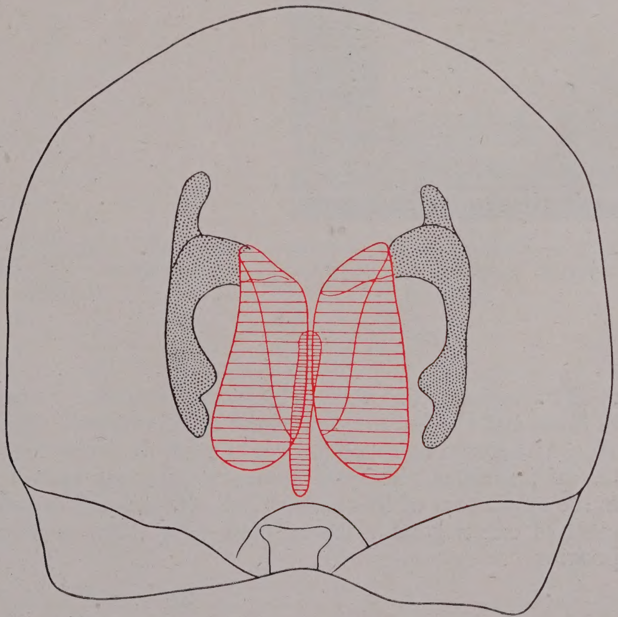

Fig. 9c — Diagram to show air (red) in the ventricles in this position.

(8) The patient is next placed in the prone position (Fig. 10a), so that air fills the posterior parts of the bodies and temporal horns, the trigones and the occipital horns (Fig. 10b). An occipito-frontal skiagram is taken (Fig. 10c). The centre ray is directed parallel with and slightly cranial to, the line between the outer canthus of the eye and the external auditory meatus, and at right angles to the film. The interventricular foramina are now submerged in fluid, and the air trapped in the third ventricle rises into its posterior part. Here it appears as a small, oval shadow between the diverging bodies of the lateral ventricles. The suprapineal recess may be seen as a small, darker area in the upper part of this shadow. If there is any question of anterior displacement of one trigone, a lateral view (Fig. 10b) is taken with the head in this position.

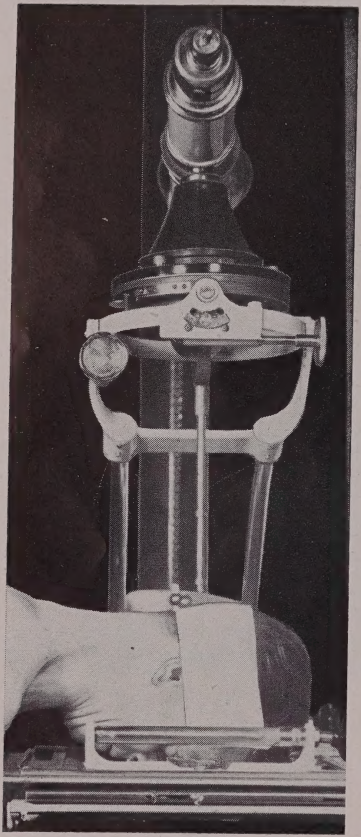

Fig. 10a—Position for the postero-anterior skiagram, the patient prone.

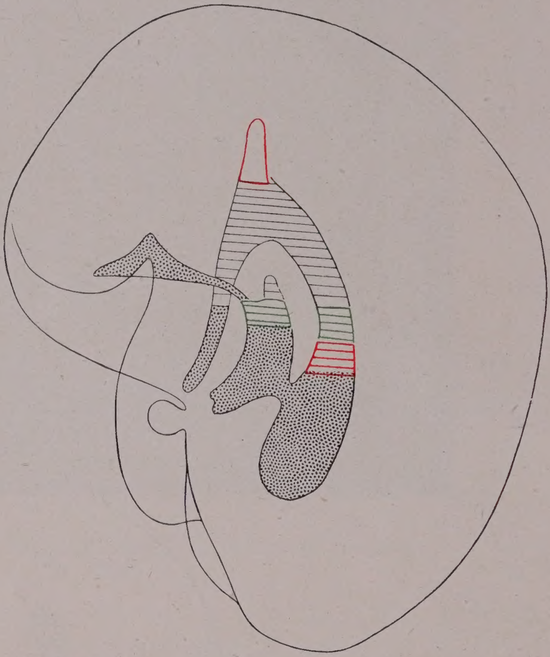

Fig. 10b—Diagram to show air in the ventricles in this position, as it would be seen if viewed laterally. The code is as in Fig. 10d.

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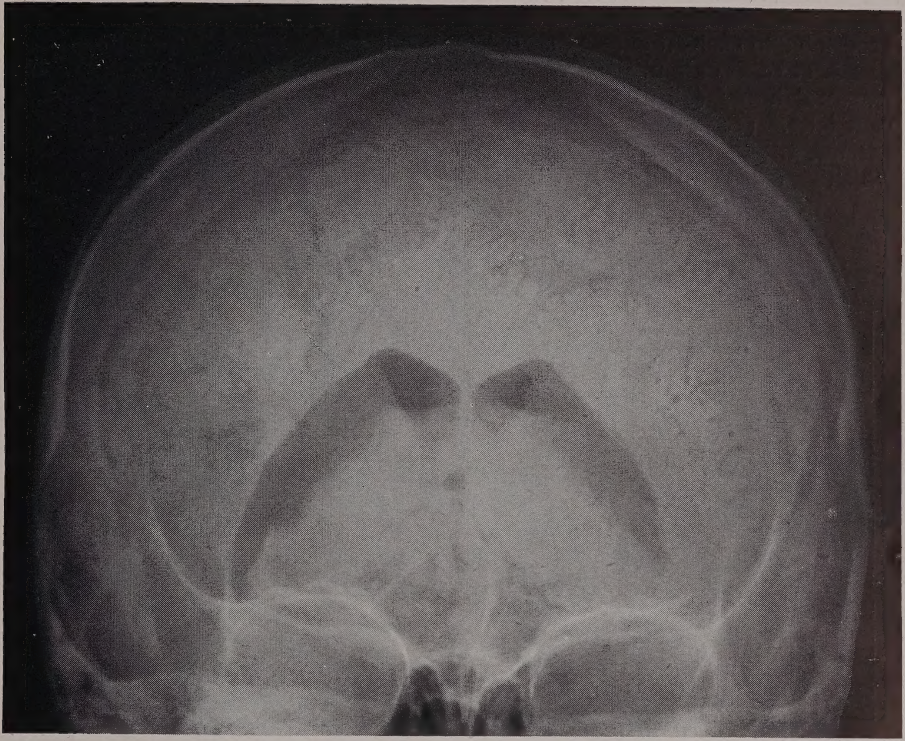

Fig. 10c—Postero-anterior skiagram.

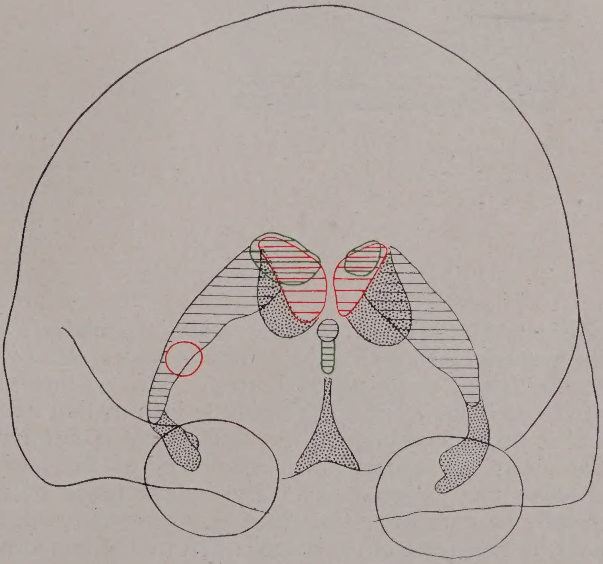

Fig. 10d—The component parts of the shadows seen in Fig. 10c (red shading, anterior part of the bodies of the lateral ventricles; red outline, occipital horn; green, middle third of bodies, and posterior part of third ventricle; black linear shading, posterior parts of lateral ventricles and suprapineal recess; black stipple, residual fluid).

(9) In earlier investigations the neck was allowed to flex by lowering the head-table to such an extent that the vertex rested upon it (Fig. 11a). When this is done the air fills the occipital horns and the posterior regions of the temporal horns (Fig. 11b) which are now the highest parts of the lateral ventricles. (It is difficult to fill the anterior portions of the temporal horns without tilting the patient's trunk downwards, for the amount of flexion which can ordinarily be attained is insufficient. The position can be most comfortably attained if a tilting table is available. Further, the shadows of the petrous portions of the temporal bones interfere with the visualization of the tips of the temporal horns). This posture was used for comparison of the occipital horns. It gives little information not afforded by other views and is uncomfortable. If the skull is not accurately disposed in relation to the centre ray considerable asymmetry of the positions of the ventricular shadows may be produced. The interpretation of abnormality must consequently be guarded. For these reasons a different method, to be described later, is now used in the examination of the temporal horns.

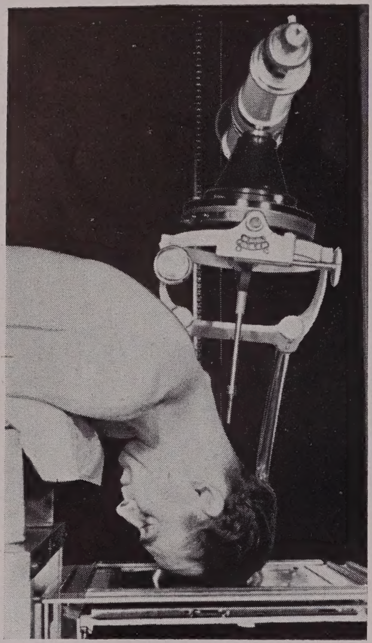

Fig. 11a—Position for the baso-vertical film.

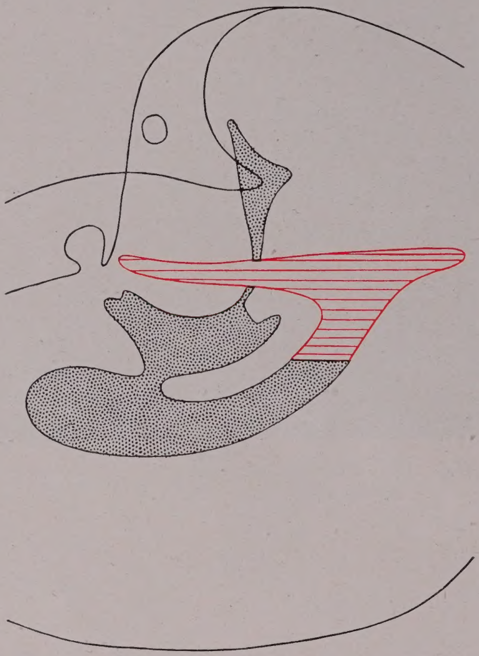

Fig. 11b—Diagram to show the distribution of air (red) in this position, as it would be seen if viewed laterally.

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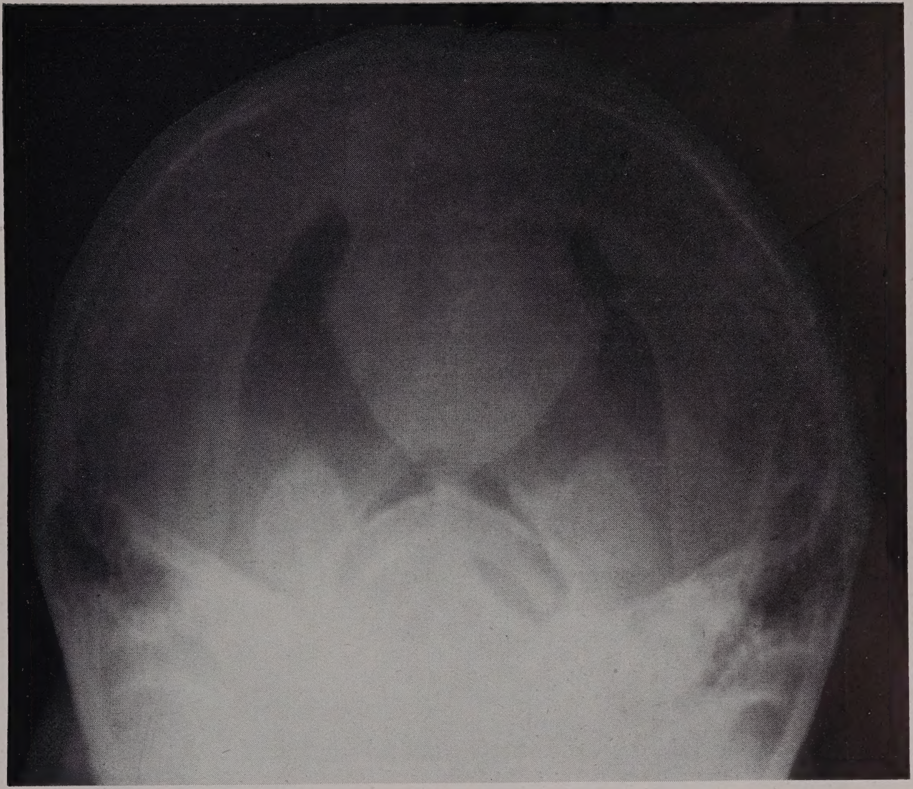

Fig. 11c—Baso-vertical skiagram.

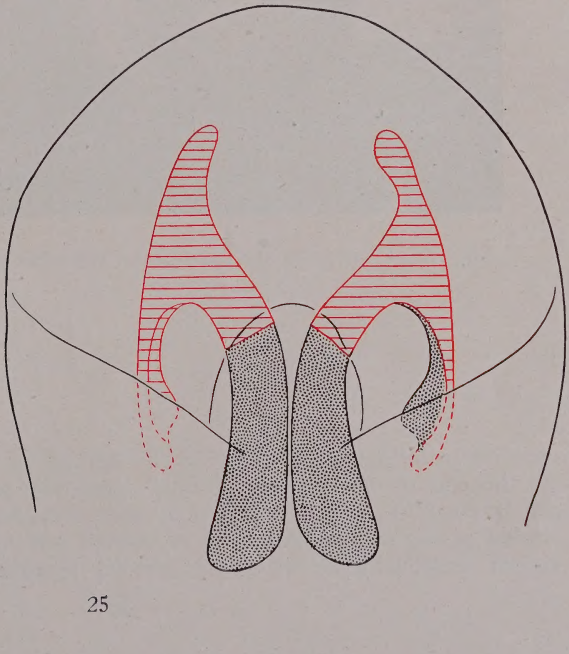

Fig. 11d—The air (red) seen in Fig. 11c.

(10) Next the patient turns on to the right side, the vertex being held upwards. The head is turned to and fro so as to encourage the passage of air through the interventricular foramina into the upper ventricle, the frontal region being kept higher than the occipital, except for a few more complete rotations which assist in the passage of air into the temporal horns. At the end of five to ten minutes' manipulation stereoscopic lateral views are taken (Fig. 12). The patient then turns to lie on his left side and a similar series of manipulations is carried out to obtain filling of the right lateral ventricle, after which stereoscopic skiagrams are again taken.

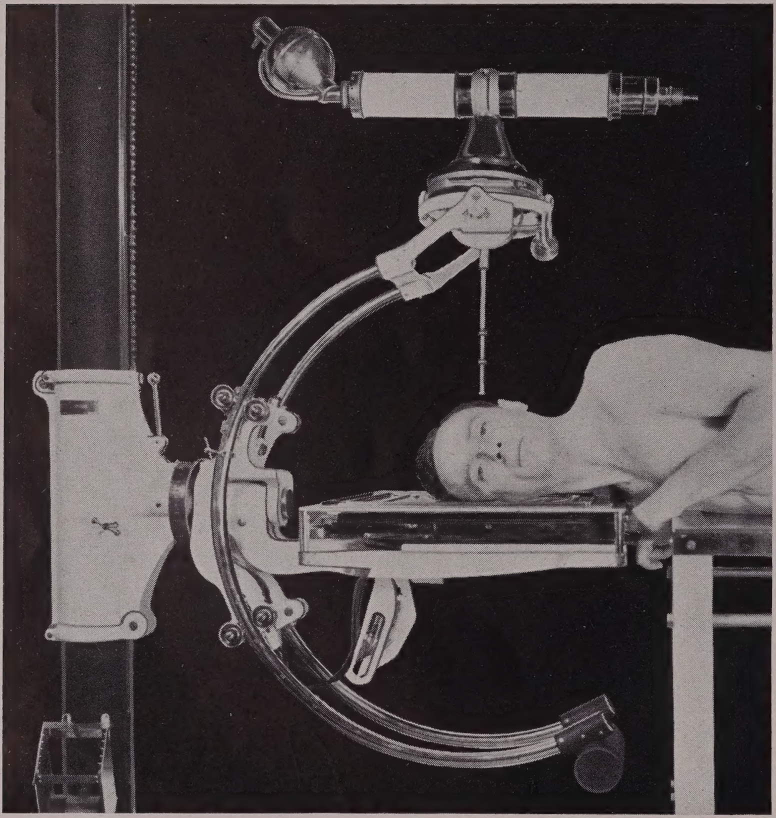

Fig. 12a—Position for the right lateral skiagram, with the patient recumbent.

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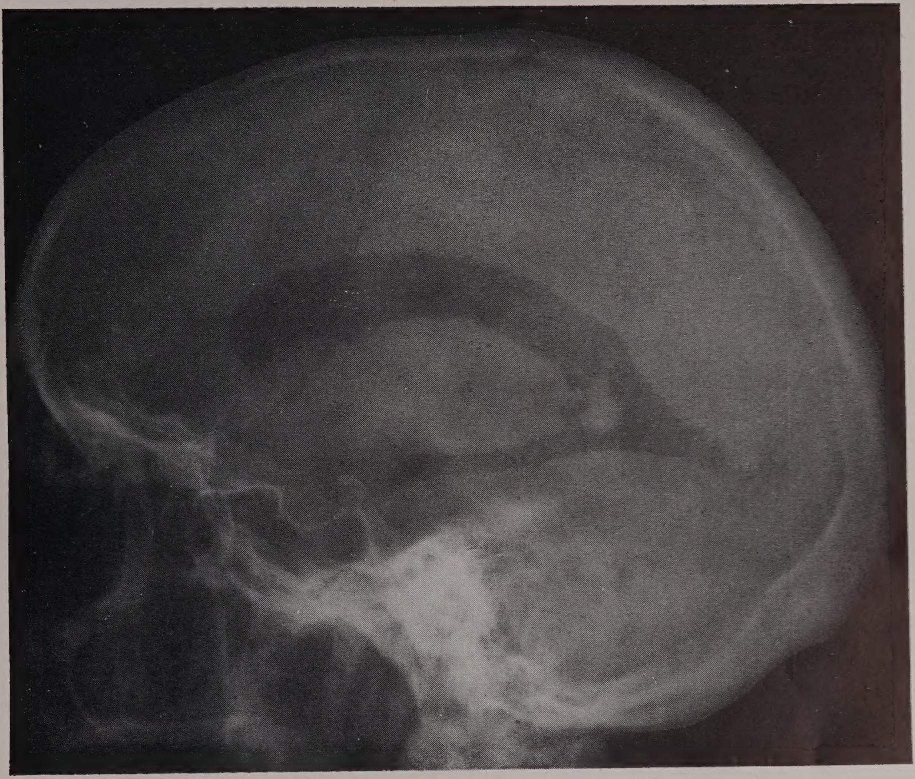

Fig. 12b—Lateral skiagram.

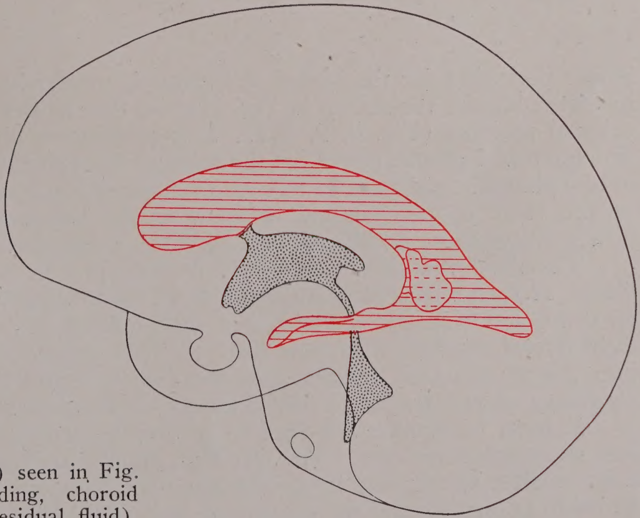

Fig. 12c—The air (red) seen in Fig. 12b (pecked red shading, choroid plexus; black stipple, residual fluid).

(11) Usually after each of these views an antero-posterior skiagram (Fig. 13) is taken, without disturbing the position of the head, to show the temporal horns. It may be taken with the aid of a Lysholm grid but the Potter-Bucky diaphragm of the head-table may be used for all exposure if, before posturing for the lateral skiagrams is undertaken, the position of the patient is altered (as shown in Fig. 12a) so that he lies at right angles to his original position (Fig. 8, 9, 10). This position of the table may be used throughout. Lysholm points out the value of this principle of taking skiagrams in two planes at right angles in each position of the head, but I was unaware of the value of this method in showing the temporal horns until it was demonstrated to me by Mr. Gilbert Phillips, of Sydney.

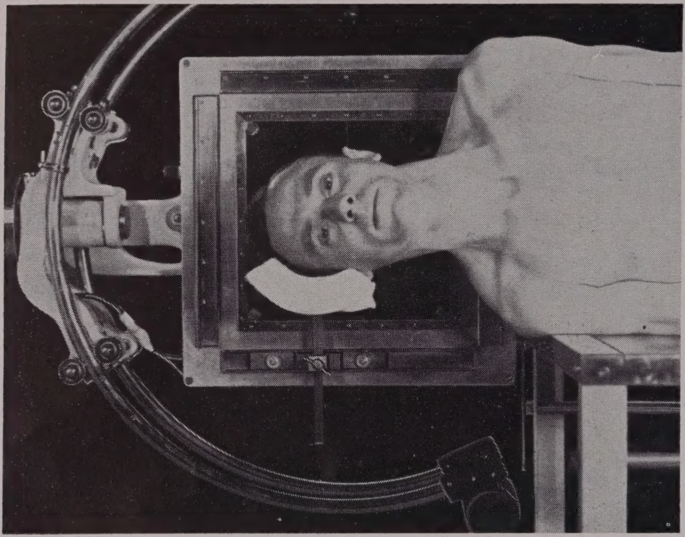

Fig. 13a—Position for the antero-posterior skiagram, the patient lying on the right side. The tube has been swung out of position to avoid obscuring the head.

The third ventricle may clearly be seen in one or other of the lateral films. A further picture may be obtained by turning the patient once more on to his left side and inclining the vertex downwards. The air from the right lateral ventricle may now fill the third ventricle. Sometimes it passes into the aqueduct of Sylvius and the fourth ventricle, but not with such constancy as to make this a useful means of demonstrating these cavities.

It must be emphasized that an unvarying procedure will not yield the best results in every case. The wet films should be studied immediately they are available, so that any further skiagrams which may appear desirable may be made before the patient returns to bed. The whole investigation should

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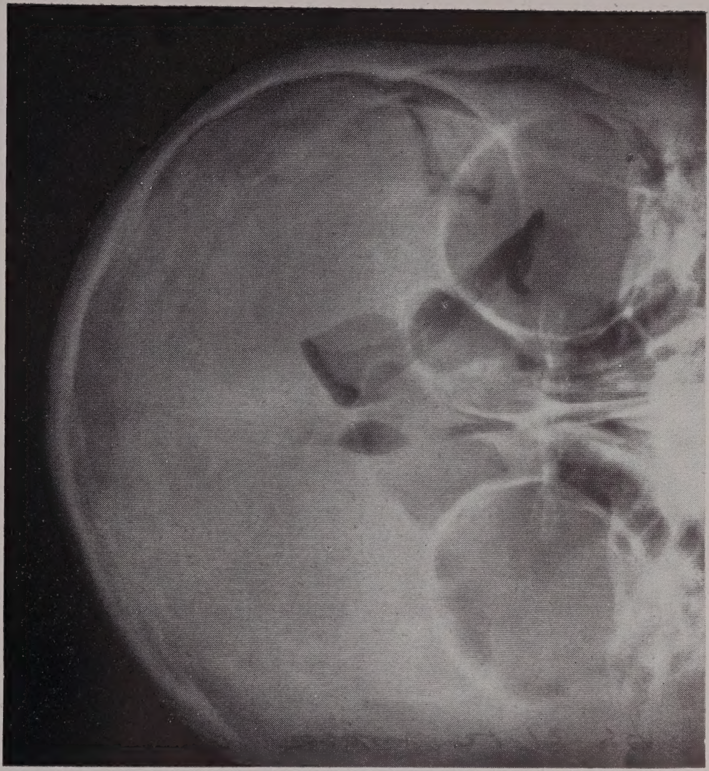

Fig. 13b—Skiagram in this position. The shadow seen above is due to air about the island of Reil.

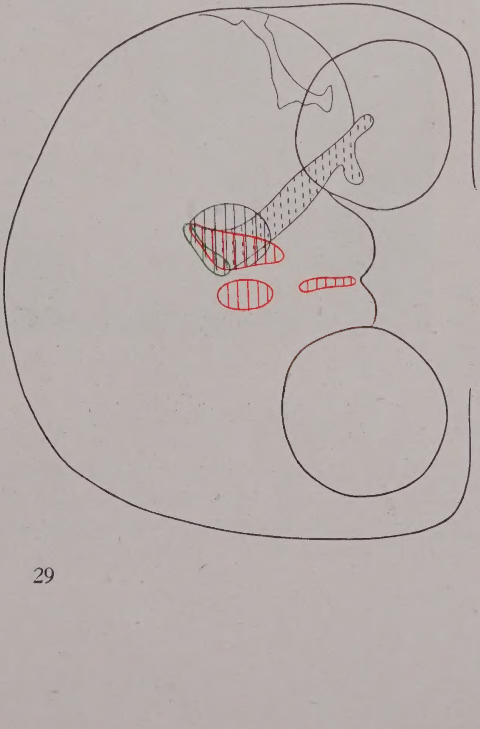

Fig. 13c—The component parts of the air-shadow seen in Fig. 13 (black linear shading, tip of anterior horn; red, anterior part of bodies, posterior part of anterior horns and third ventricle; green, middle third of body; pecked black shading, posterior part of body, trigone and temporal horn). Reference to Fig. 46a shows that little of the temporal horn, except its anterior extremity, is seen.

be directed to the elucidation of whatever abnormality is at the outset considered most likely to be present. In the usual procedure the number of films taken can be reduced. When the lesion is in the cerebral hemispheres one postero-anterior film may provide a sufficient guide to the progress of filling. It is then unnecessary to take other films in the erect posture.

The time occupied by the whole procedure is usually from sixty to ninety minutes.

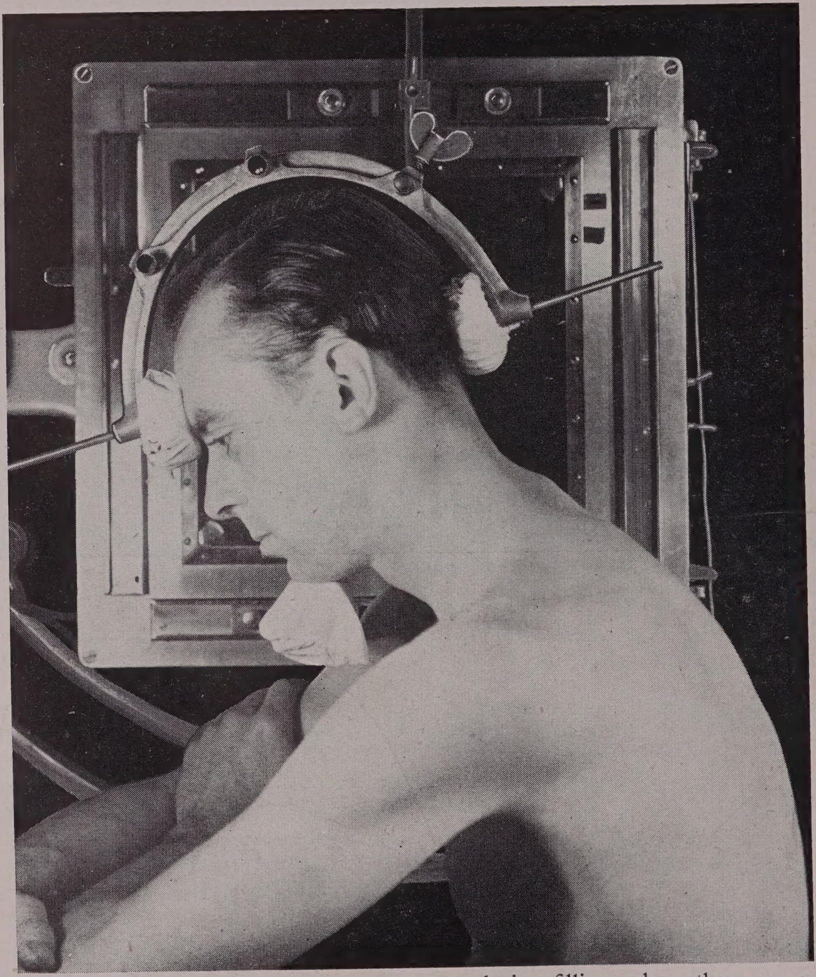

Fig. 14—Position used for lateral skiagrams during filling, where these are a main object of investigation.

Lateral Skiagrams During Filling

Considerable information may be obtained from lateral skiagrams taken at various stages of filling. If postero-anterior views are unnecessary, clearer lateral films may be obtained by the following departure from the usual procedure. At the commencement the chair is so placed that the patient sits at right angles to the usual position. One of his shoulders rests against the vertical head-table which is now parallel with the sagittal plane of the head (Fig. 14). The head is kept flexed by a standard head-clamp, which is so arranged that one pad is in contact with the forehead and supports the weight of the head, while the other presses lightly on the occiput. In order to obtain better fixation of the head, curved supports similar to those used for the vertex may be substituted for the conventional round pads. A long chin-rest, adjusted to the lower edge of the head-table, gives further support. Since the head is separated from the film by the breadth of the patient's shoulder, a fine-focus tube is used, with the target at a distance of six feet from the film. It is arranged so that the centre-ray passes just behind and above the mastoid processes.

Cisternal Injection

The introduction of air directly into the cisterna magna has been used as a routine method by some workers. A fine needle with a three-way tap may be used. A length of 12 cm. of rubber tubing of 3 mm. bore, with a short length of glass tubing on one end, is attached to one outlet. The patient may sit in the usual position with his head firmly fixed in slight flexion. Skiagrams may be taken without interrupting the course of filling if instead the sagittal plane of the head is parallel with the vertical head-table (Fig. 14). In order to secure firm fixation the round pads of the conventional head clamp are replaced by long, curved head supports of the type already described, and illustrated in figure 5a. The needle is inserted so that the tip enters the lower part of the cistern below the foramen magnum. When the point has been felt to pierce the spinal membranes, the stylet is withdrawn. The tap is turned immediately the stylet is removed, so that the cerebrospinal fluid communicates with the manometer tubing. The level which the fluid assumes is noted. This is usually about the level of the cisternal needle. In several cases the pressure was measured by means of a U-tube containing water, before any fluid was run off. With the neck in the slightly flexed position the pressure was found to be between 8 and 30 mm. above that of the atmosphere. The needle must be held firmly in position during the remainder of the investigation. It is not difficult to achieve this manually but the use of a retentive device may be found convenient. A metal disc, 1½ inches in diameter, carries on one side a boss. A slot is cut through disc and boss from the periphery to the centre, allowing the disc to be slipped into position over a needle. A set-screw passing through the boss is tightened to hold the needle in position. Tapes, attached to two lateral holes in the disc, are tied around the root of the nose.

Five c.cm. of air are introduced through a flexible connection, and an equivalent amount of fluid is allowed to run from the dependent manometer tubing. This procedure is continued until a satisfactory filling is obtained. At the end of the procedure the pressure should be much the same as the initial pressure. If the tip of the needle is introduced too high in the cistern an accumulation of air in this region may prevent evacuation of fluid until the air has entered the ventricles, displacing fluid into the cistern as it rises. For this reason it is best to introduce the needle as near to the arch of the atlas as possible.

By this method air is introduced directly into the cisterna magna and, if the ventricular passage offers little resistance, it will all pass into the ventricles. However, this end can be achieved as efficiently when the air is introduced into the lumbar theca, although it is necessary to introduce the air more slowly. The rapid introduction of air into the cisterna magna produces less discomfort than a similar rate of injection through a lumbar needle. The upward passage of large volumes within the spinal theca produces pain and shock. If, however, the air is introduced slowly there appears

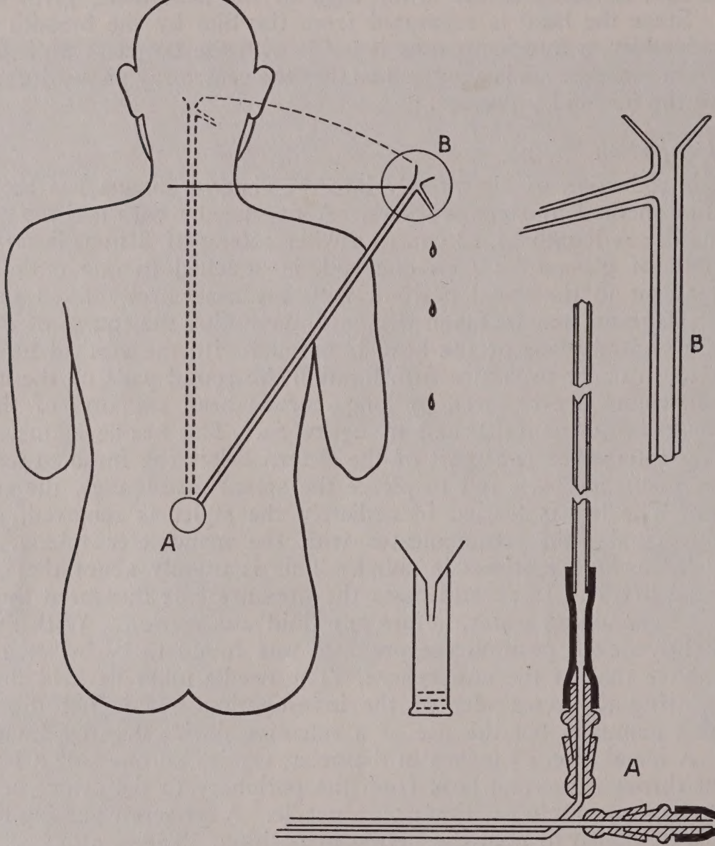

Fig. 15—The method employed to keep the intra-cranial pressure steady during extensive fillings. A double needle is used, flexibly connected to a syringe and a manometer tube (detail at A), the upper end of which has a convenient spout (detail at B), from which fluid overflows into a measure. By lateral inclination the spout is kept at the level to which the fluid originally rose.

to be no difference in the comfort of the patient, and indeed there are limits to the rapidity with which it is wise to introduce air into the cisterna magna. Patients vary in their sensations, but most were found to remain comfortable if two minutes were allowed for the injection of each 5 c.cm. of air. Headache commences when much the same volume of air has been introduced by either method, and there seems to be no difference in the subsequent reaction. As the filling of selected parts of the subarachnoid space depends upon the position of the neck, the lumbar method has wider applications. However, the basal cisterns may be filled by the cisternal method, either by increasing the rate of injection or after the ventricles are filled.

When air introduced by the lumbar method enters the subdural space cisternal injection is the surest method of securing ventricular filling. The cisternal method must be used when it is desired to fill the ventricles in the presence of a spinal subarachnoid block. This was apparently produced in one child by coagulation of blood around the spinal cord. In another child it proved impossible to obtain more than a few drops of fluid at successive lumbar punctures, and injected air was forcefully returned. Cisternal injection was used in both cases.

The ventricles may be filled as efficiently by one method as the other. The cisternal injection may be more rapid, but the lumbar method allows more selective filling of particular areas of the subarachnoid space. The maximum of safety is very important in a non-essential diagnostic procedure, and lumbar puncture is safer than cisternal puncture. For these reasons, after a period of trial, a return was made to the lumbar method.

The Posterior Fossa

For the investigation of lesions in the posterior fossa a special modification of the technique has been used. The patient sits with his neck flexed to ensure ventricular filling, forehead and nose being against the head-table. Lumbar puncture is performed, using a double-barrelled needle. The manometer is not attached. Five to seven c.cm. of air are slowly injected over a period of five minutes. After the injection has been commenced fluid is allowed to drip from the second barrel at about the same rate as the air is injected. If a plain needle is used, air may be injected and fluid withdrawn in one or two successive small amounts. During the introduction of the last cubic centimetre of air a postero-anterior skiagram is taken, the centre ray being horizontal. At the end of the injection a lateral view is taken without altering the position of the patient's head. To avoid moving the tube of the Schönander table a portable tube stand is used. Satisfactory pictures of the fourth ventricle are thus consistently obtained with the introduction of limited amounts of air. If a tumour is in question this may be of considerable importance. If adequate pictures are not obtained, and the patient's condition remains satisfactory, an attempt may be made to secure better definition by the use of a larger volume of air.

The Subarachnoid Space

In the routine procedure described the ventricular system alone is usually filled, so that unobscured shadows are obtained. Sometimes, however, filling of the subarachnoid cisterns and sulci is desirable. The size of structures intervening between the ventricles and the cisterns may then be estimated. Gardner and Nichols (1933) have reported two cases with papilloedema, in which the ventricles were undisplaced and undistorted. Absence of the convolutional pattern over a limited area served to indicate the position of a tumour. It may, therefore, be useful to outline the sulci where, although a tumour is suspected, the ventricles have been found to be normal. In other cases evidence of cortical atrophy or arachnoiditis may be found.

Where there is clinical evidence serving to localize the pathological lesion, an attempt should be made to demonstrate the sulci over the region.

When a large amount of air is to be used it becomes important to reduce the shock of the procedure and the subsequent reaction by keeping the intracranial pressure constant. The following method is simple and has been found effective. A special manometer-tube is used, having a short, open side-tube near its upper end (Fig. 15). Lumbar puncture is carried out, using a double-barrelled needle. The lower barrel is used for the evacuation of fluid; the upper one, fitted with a tap, for the introduction of air. Alternatively, two single needles may be used. The manometer-tube is connected with the lower barrel by a short length of rubber-tubing. The cerebrospinal fluid is allowed to rise in the tube and its final level is noted. The tube is now inclined until the fluid drips from the spout. If the intracranial pressure is now increased cerebrospinal fluid will overflow until the original pressure is restored. Filtered air is introduced through the other barrel of the needle, from a twenty-cubic-centimeter syringe. As air enters the subarachnoid space fluid drips from the manometer-tube. A constant intracranial pressure is thus maintained, so long as the fluid in the spinal portion of the subarachnoid space is not replaced. The quantity of fluid flowing away is in practice almost identical with the amount of air injected, although it may be slightly greater by reason of continuing production. A skiagram taken after the introduction of 100 c.cm. will show whether further air is necessary.

Smaller quantities of air may be used when it is desired to visualize a limited area of the subarachnoid space. The patient is placed in a laterally-inclined position after antero-posterior and lateral views of the ventricles have been taken. The side of the suspected lesion is kept uppermost, and progressive replacement carried out until a satisfactory skiagram of the sulci is obtained. Often 20 c.cm. will suffice. After taking stereoscopic lateral views, antero-posterior and postero-anterior skiagrams are taken. It is sometimes desired to fill the subarachnoid space over both frontal poles. This may be done by introducing air while the head and neck are extended.

When, after ventricular filling has been carried out, and the needle is withdrawn, it is possible to obtain satisfactory films of limited zones of the subarachnoid space without resorting to this further replacement. The patient sits up, then lies back over the end of the table, supported by assistants, so that his spine is dorsiflexed as far as possible. This serves to transfer air into the anterior horns. Gentle shaking then assists the escape of as much air as possible from the ventricles into the cisterns in the posterior fossa and into the spinal subarachnoid space. The patient next is brought into the sitting posture with his neck extended. The head may be inclined so that the side of the suspected lesion is uppermost. The supine position is then resumed and the necessary films taken.

Success in showing the particular feature towards which the investigation is directed may require some patience. It may be necessary to take several skiagrams after the introduction of progressive quantities of air. It is not sufficient merely to carry out a routine encephalography, but rather each investigation must be regarded as a search for a suspected abnormality.

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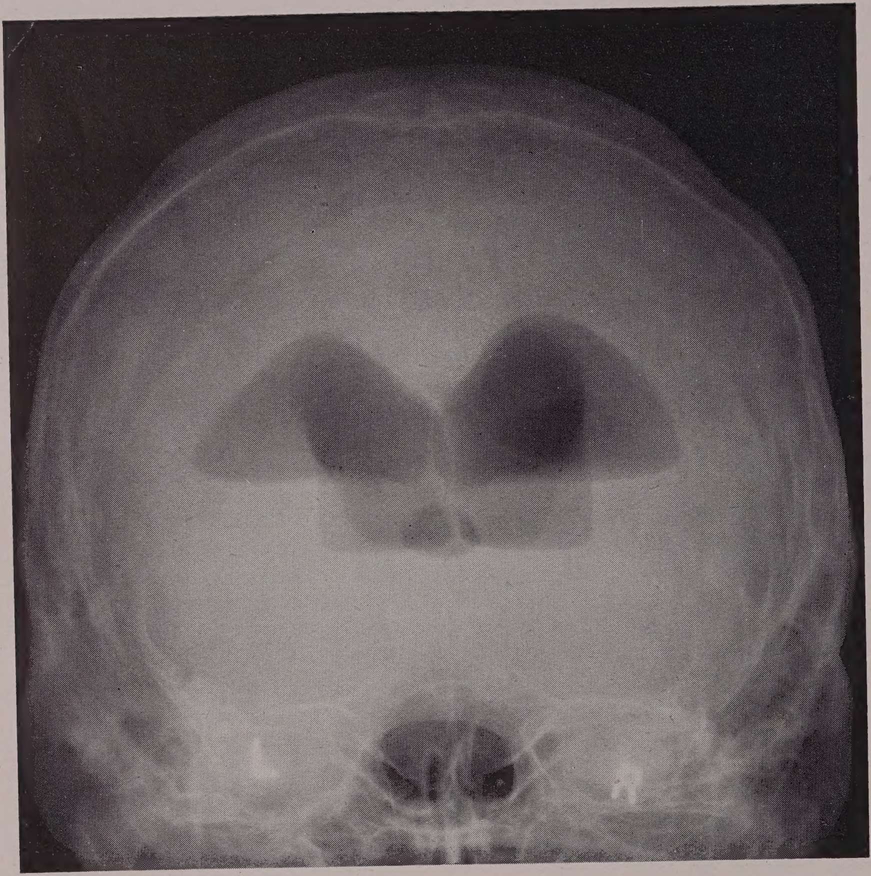

Fig. 16—Skiagram demonstrating exclusive filling of the ventricles (120 c.cm.) in a case of hydrocephalus.

Chapter III

TECHNICAL RESULTS

At the time of writing, there are available for analysis some two hundred and eight cases and certain technical aspects of these will now be considered.

Efficiency of Filling

The desired filling was obtained in two hundred and one cases. When the purpose was to visualize the ventricles alone, it was usually found that about 20 c.cm. of air give the clearest definition of ventricles of normal size. When greater quantities were used, the air usually commenced to pass into the general arachnoid space and obscured the ventricular outlines. In a case of hydrocephalus, it was possible to introduce 120 c.cm. of air into the ventricles (Fig. 16) before any air appeared in the subarachnoid space.

In seven cases air could not be induced to enter the ventricles. The reasons for success and failure will be analysed later.

Reaction

The patient usually remains comfortable during the introduction of the first 15 c.cm. of air. After this he may complain of headache, and at the end of the procedure there may be pallor and sweating. The pulse rate may be slightly increased or decreased. Vomiting occurred in a small proportion of those patients in whom larger quantities of air were used. Two patients fainted, but this occurred in one before the introduction of air was commenced, and in the other before the lumbar-puncture needle was inserted. In each instance the investigation was continued after a pause. By securing the escape of air into the subarachnoid space at the end of the procedure the headache may be temporarily increased, but the patient feels normal more quickly than if the air is left in the ventricles. The air is absorbed much more quickly from the subarachnoid space than from the ventricles where its presence may be demonstrated in some cases by skiagrams taken a week after the introduction. Some patients feel well the day after encephalography, but they are usually kept in bed for four or five days. During the first few days coughing or sitting up may induce headache, which quickly subsides when the patient lies down. When, for any reason, it has been desired to repeat the investigation the patient has always willingly submitted to it.

Therapeutic Effect

Except in the cases of localized headache following trauma, in which the procedures described by Penfield (1927) may be of value, it is believed that, in itself, encephalography has no therapeutic effect. In as complete a follow-up as possible, no patient stated that he was worse; most said that they were better, and a number claimed great benefit from the "treatment" they had received. In epileptics this was probably due to the institution of adequate medical treatment. In children there sometimes occurred a prolonged period of freedom from previously frequent attacks. In some patients psychological factors undoubtedly contributed to the improvement experienced. In some the statement could well be explained by a wish for ultimate freedom from the distressing symptoms, and a desire to reward with good results those who had shown them care and attention. In patients with psychogenic disorders the procedure probably has a pronounced suggestive effect.

Mortality

In the series of two hundred and eight cases one patient died thirty-six hours after the investigation. In this instance a complete replacement was performed under avertin anaesthesia. The patient, demented and aphasic for some years before the investigation, did not recover consciousness after it. It must remain open to doubt whether death was due to the procedure or to the anaesthetic. Another patient (H.T., whose clinical history is recorded on page 4) died thirty-six hours after operation following encephalography, due to herniation of an astrocytoma of the temporal lobe through the incisura tentorii. A third patient died following operation performed some hours after the injection of 5.c.cm. of air, which reached only the subarachnoid space. An aneurysm of the middle cerebral artery, 1 cm. in diameter, was found pressing into the uncus, into which haemorrhage had occurred. It was not thought that encephalography was responsible for the patient's death. It is wise, however, to avoid encephalography if the presence of an aneurysm is suspected. In a large number of encephalographies performed since this series was completed there have been no fatalities.

Davidoff and Dyke (1937) report only nine deaths in their series of four thousand cases. Two patients had intracranial aneurysms. Four patients had cerebral tumours, one in the third ventricle, one in the cerebellum and two in the cerebrum. One patient, a middle-aged man, died of coronary occlusion six hours after the procedure. These results, and those of other workers, suggest that the patients who are likely to succumb are those suffering from cerebral neoplasms, aneurysms or arteriosclerosis.

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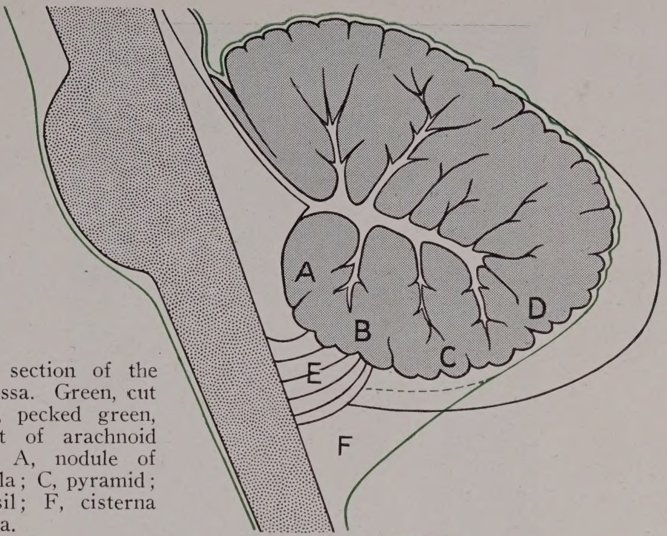

Fig. 17a—Midline section of the posterior cranial fossa. Green, cut edge of arachnoid, pecked green, line of attachment of arachnoid over cerebellum. A, nodule of cerebellum; B, uvula; C, pyramid; D, tuber; E, tonsil; F, cisterna magna.

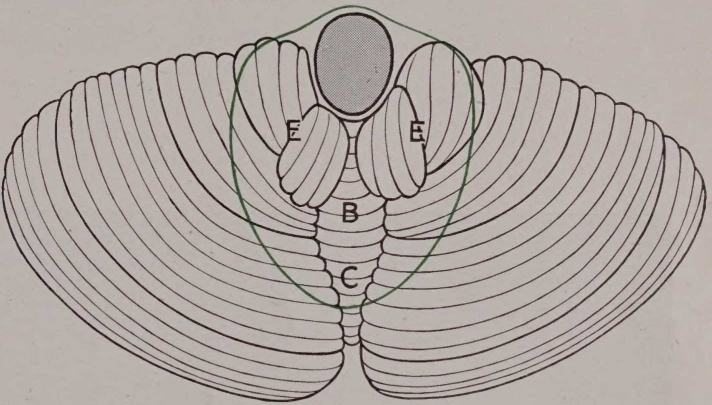

Fig. 17b—Inferior aspect of the cerebellum. Code as in Fig. 17a.

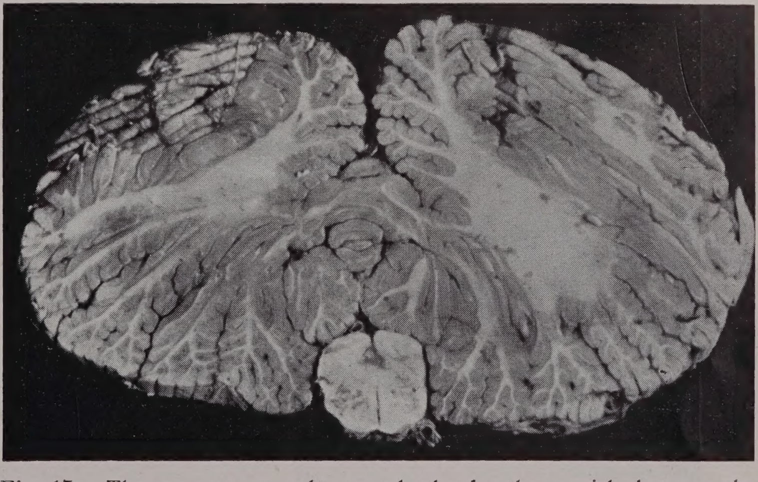

Fig. 17c—The passage upwards towards the fourth ventricle between the medulla and the cerebellar tonsils.

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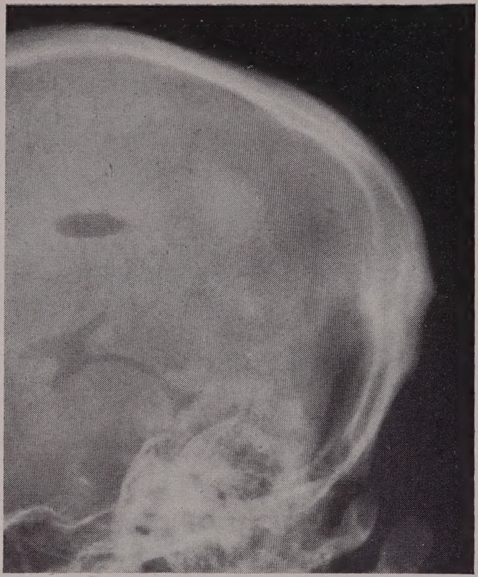


Fig. 17d—Skiagram after the introduction of 10 c.cm. The cisterna magna is clearly seen and air is slowly entering the ventricular system.

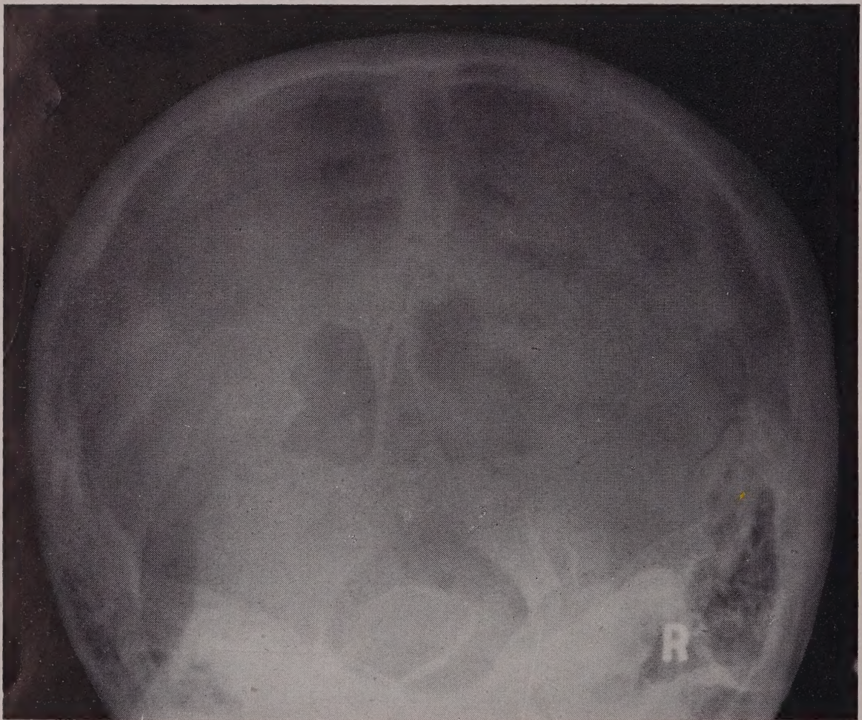


Fig. 17e—Occipito-frontal skiagram. Air is seen in the cisterna magna.

To face page 37.

Chapter IV

ROUTES TAKEN BY THE AIR

Within the skull the air may pass upwards in the ventricular system, in the subarachnoid space, or in the subdural space. It seems extraordinary, at first sight, that air injected into the lumbar theca should pass into the ventricular system; but a consideration of the anatomical and physical factors robs the matter of much of its mystery.

Anatomical Considerations

For convenience of description in this section, the terms anterior or ventral, and posterior or dorsal, are used as having reference to a line passing through the long axis of the brain stem. Superior or above, and inferior or below, are used as having reference to the long axis of the skull.

The arachnoid over the spinal cord is continuous, through the foramen magnum, with that over the brain. The membrane covering the anterior aspect of the spinal cord is continuous with that covering the anterior aspects of the medulla and pons, as shown in figure 17a. After leaving the dorsolateral aspect of the spinal cord the arachnoid extends as a thin sheet to meet the cerebellum along a line which extends over the tonsils, or further laterally, over the biventral lobules (Fig. 17b). More posteriorly it is closely applied to the pia mater over the medial parts of the biventral lobules, and occasionally more posteriorly still over the medial parts of the inferior semilunar lobules. In the midline, the posterior attachment extends across the pyramid of the vermis, or more posteriorly across the tuber. Thus, in bridging the space between the medulla and the cerebellum the arachnoid bounds a wide expansion of the subarachnoid space—the cisterna magna (cisterna magna cerebellomedullaris). The posterior surface of the medulla forms the anterior boundary of the cistern. Laterally the tonsils of the cerebellum project downwards into the cistern, and between these there is a deep vertical cleft, the vallecula, which extends upwards to the vermis (Fig. 17b). Near the apex of this deep part of the cistern, posterior to the medulla (Fig. 17c) is the foramen of Magendie (Fig. 25), which opens into the fourth ventricle. Extensive potential communication exists between the cisterna magna and the subarachnoid space over the anterior surface of the medulla, the passages lying between the medulla and the closely applied medial surfaces of the tonsils of the cerebellum and below the tonsils.

Distribution of the Air

If a series of lateral views are taken during filling in the usual posture with the head flexed, the air is seen to pass through the foramen magnum in a broad column posterior to the spinal cord, as shown in figure 22a. It enters the cisterna magna and rises to its upper part (Fig. 17d.). In postero-anterior skiagrams the air may be seen in this situation as a faint shadow covering a large area of the occipital bone (Fig. 17e). The upper and lateral margins of the shadow are usually irregular and the lower margin horizontal In this case the shadow measures 5·4 cm. wide by 3·8 cm. vertically, and extends from 1·5 cm. above the foramen magnum to the internal occipital protuberance. The shadow is usually narrower than that illustrated, and may extend from the foramen magnum to the internal occipital protuberance. It usually appears as a paired shadow, the division corresponding to the internal occipital crest. A denser median shadow may be seen corresponding to the deep part of the cistern leading to the foramen of Magendie. The accumulation of air which sometimes results, and which remains in the cisterna magna while the patient's head is erect, leaves little doubt that the further passage of air over the inferior surface of the cerebellum is impeded. This has its anatomical explanation in the extent of the cisterna magna and its limitation by the close application of pia and arachnoid.

Two factors may be responsible for the passage of air into the cisterna magna. Firstly, in passing upwards through the cerebrospinal fluid, the air will tend to take the most vertical path available to it. In the sitting patient with flexed head, the air thus tends to rise to that part of the subarachnoid space posterior to the cervical spinal cord. Secondly, the subarachnoid space is wider posterior to the spinal cord than it is anteriorly. For reasons which will be given later, the first explanation accounts satisfactorily for the direction of passage of air during encephalography.

When the air has filled the posterior part of the cisterna magna down to the level of the lowest part of the vermis it will commence to pass anteriorly in the highest part of the space between the tonsils of the cerebellum. A varying proportion will rise directly from the spinal theca into the anterior part of the cistern. Rising between the tonsils of the cerebellum and the medulla (Fig. 17) the air thus enters the region of the foramen of Magendie. Passage anteriorly from the cistern is apparently hindered by the close apposition of the tonsils with the medulla (Figs. 17b and c). Only a few filaments join these surfaces, so that this is a potentially available pathway; but apparently it offers greater resistance to the passage of air than does the ventricular pathway. The air might pass below the tonsils of the cerebellum to the subarachnoid space anterior to the medulla, but this occurs only if a large quantity of air is injected rapidly, for the passage lies at a lower level.

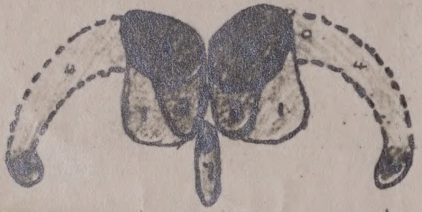
In those patients in whom it has proved impossible, by any manoeuvre, to fill the ventricles, the air has been seen to accumulate in the cisterna magna and over an unusually long portion of the subarachnoid space posterior to the spinal cord. When the air fails to enter the fourth ventricle there is apparently considerable resistance to the escape of air from the cisterna magna, for so long as the head remains flexed air passes into the general subarachnoid space anterior to the medulla and pons only when a large quantity has accumulated behind the upper part of the spinal cord. If before this stage is reached the patient's head and neck are dorsi-flexed, the air rapidly passes anterior to the upper part of the cervical spinal cord and medulla, into the pontine and interpeduncular cisterns.

Effect of Alteration of Posture

If the head and neck are extended at the beginning of the injection, the air does not enter the ventricular system, but is first seen within the skull in the cisterna pontis, anterior to the pons. In this posture, owing to its

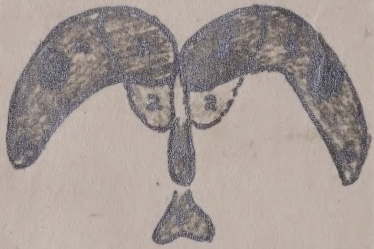
The appearances on the film in each position are shown in the following diagrams.

(1) Face up- - stereo posterior.

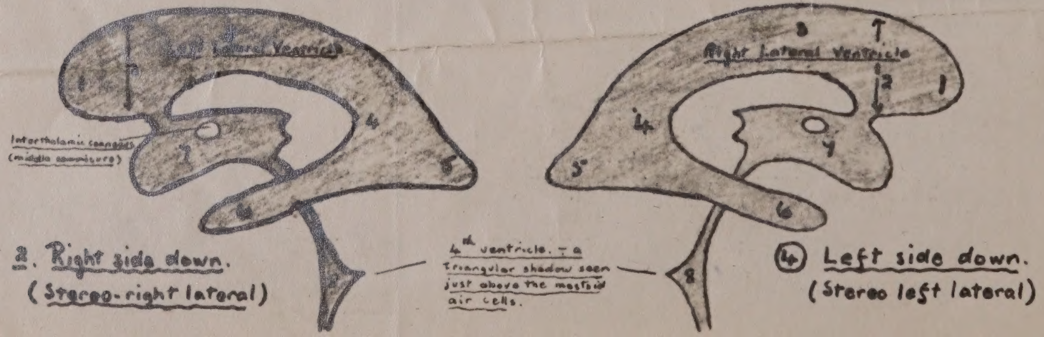


(1) Anterior horn of lat. ventr
(2) Junction of ant. horn & bod
(3) Main part of body of lateral ventricle.
(4) Posterior part of body.
(5) Posterior horn.
(6) Inferior horn
(7) Third ventricle.
(8) Fourth ventricle.

(3) Face down - stereo anterior.



(2) & (4) Side down - stereo laterals.


Left Lateral Ventricle
3
2
1
4
7
6
5
Interthalamic connexus
(middle commissure)
Right Lateral Ventricle
3
2
1
4
7
6
5
8

2. Right side down.
(Stereo-right lateral)

4th ventricle. - a triangular shadow seen just above the mastoid air cells.

④ Left side down.
(Stereo left lateral)

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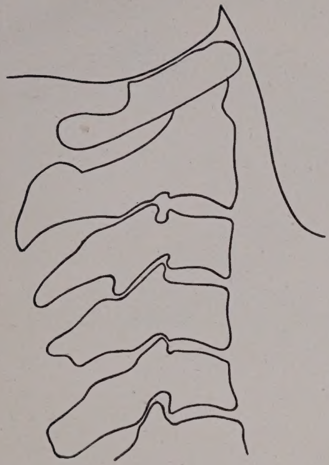

Fig. 18a—Tracing of skiagram of cervical vertebrae with head erect.

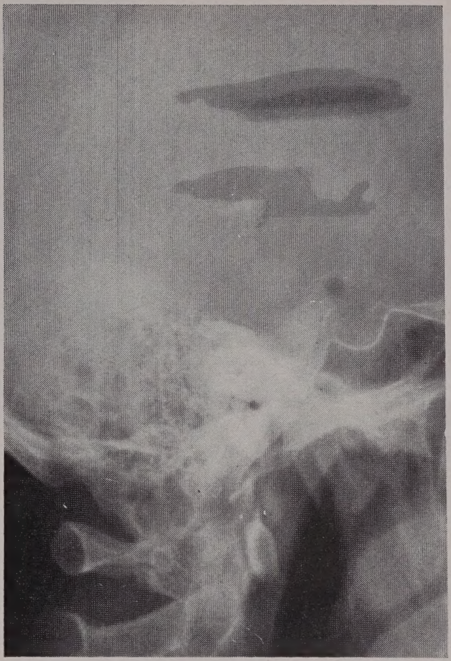

Fig. 18b—In this posture air passes largely into the ventricle, but some usually passes into the basal cisterns. A small bubble is seen in the interpeduncular cistern.

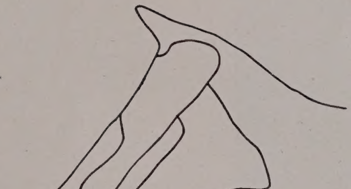

Fig. 18c — Cervical spine with head and neck extended.

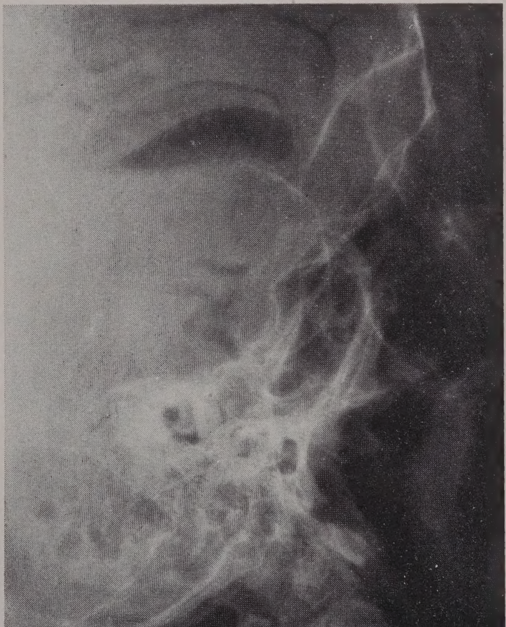

Fig. 18d—In this posture air passes into the pontine cistern, the interpeduncular cistern, and sulci on the medial aspect of the hemispheres.

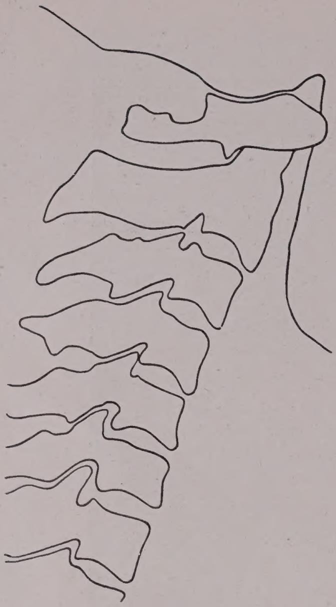

Fig. 18e — Cervical spine with head and neck slightly flexed.

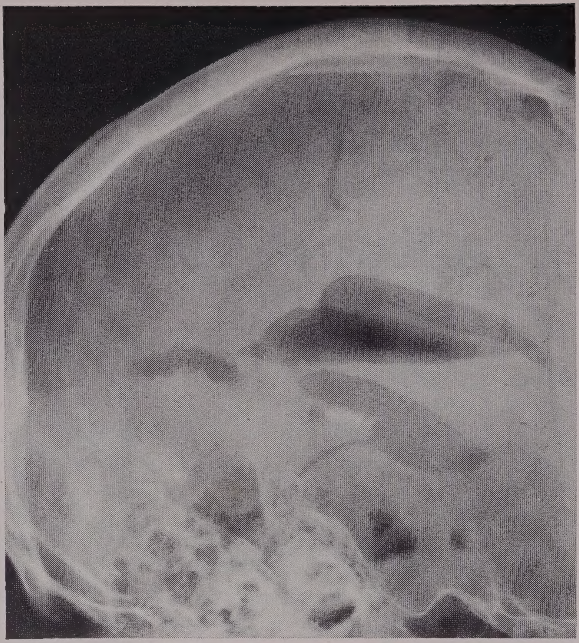

Fig. 18f—The air once again enters the ventricular system.

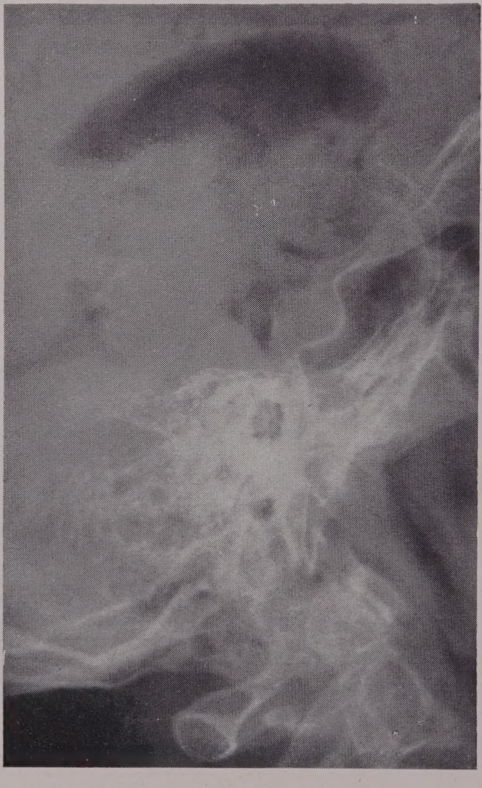

Fig. 18g—The head and neck are again extended. The basal cisterns and the cerebral sulci are once again being filled, but no air enters the fourth ventricle.

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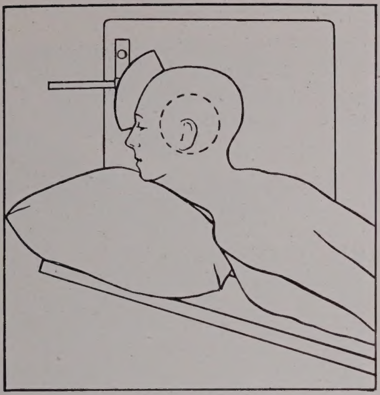
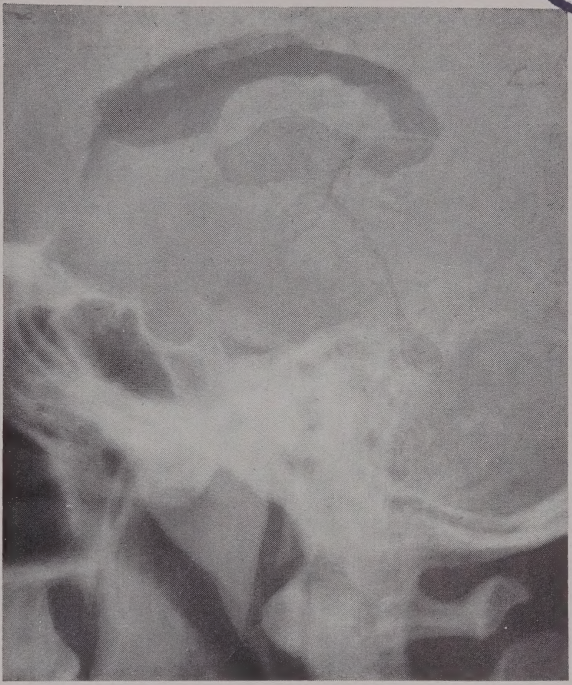


Fig. 19a—The patient lies prone on an inclined plane with his head extended.

Fig. 19b—The air rises to the dorsal part of the cervical theca and passes into the ventricular system.



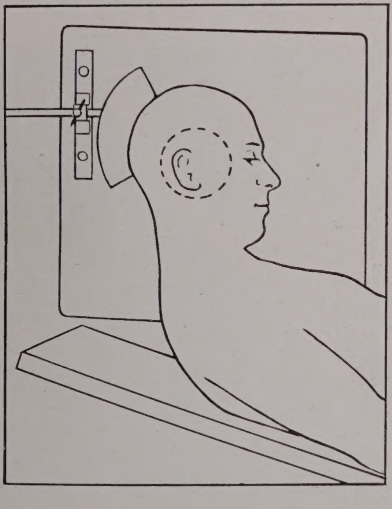
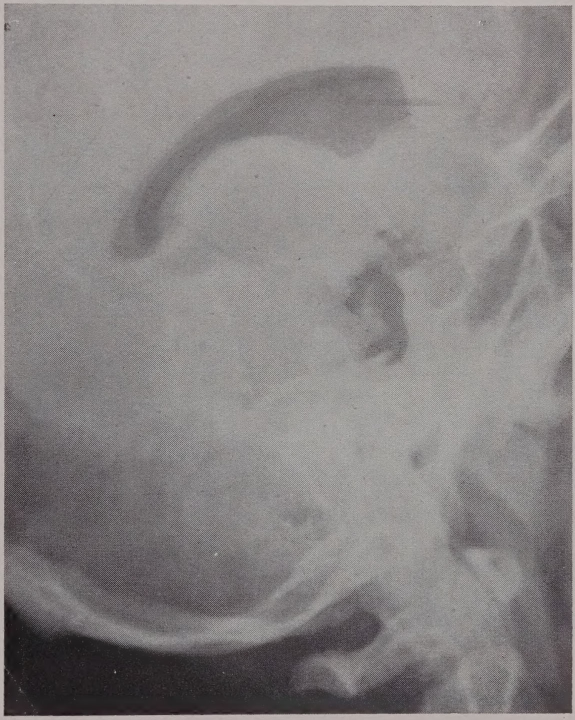


Fig. 19c—The patient next lies supine on the inclined plane with his head flexed.

Fig. 19d—The air rises to the ventral part of the cervical theca and passes into the pontine and interpeduncular cisterns.



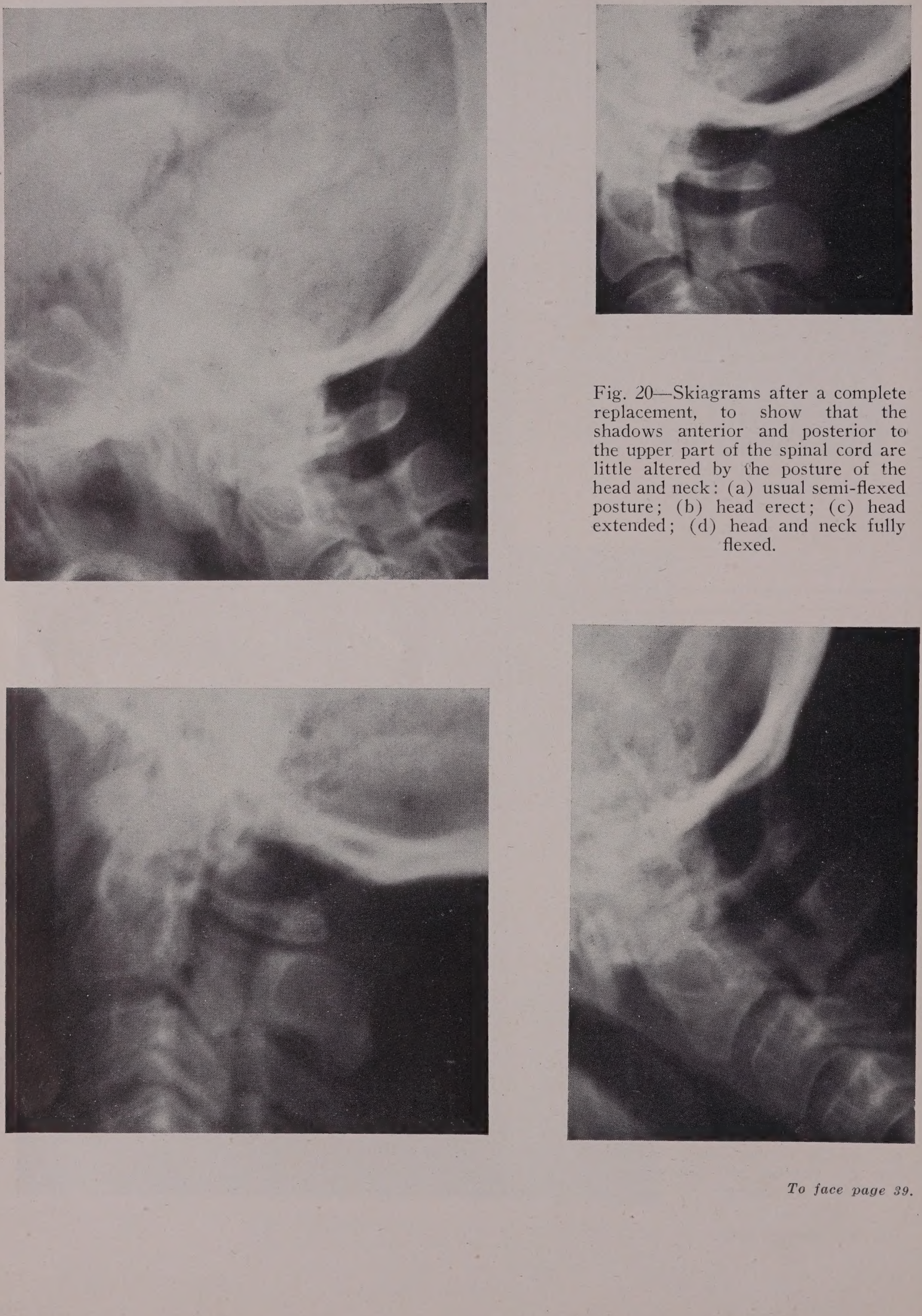


Fig. 20—Skiagrams after a complete replacement, to show that the shadows anterior and posterior to the upper part of the spinal cord are little altered by the posture of the head and neck: (a) usual semi-flexed posture; (b) head erect; (c) head extended; (d) head and neck fully flexed.

buoyancy, the air tends to rise to the anterior part of the subarachnoid space in the cervical canal. The cisterna magna does not fill, and there is no column of air posterior to the spinal cord.

It is more difficult to demonstrate the air anterior to the spinal cord, for by this anterior route it passes upwards more rapidly. It can flow into the wide cisterns anterior to the medulla and pons more quickly than through the cisterna magna into the ventricular system. Further, the shadows of the dense condyles of the occipital bone and of the mastoid processes tend to obscure this region. In the erect posture the cervical theca is almost vertical (Fig. 18a). There is some tendency for a little of the air to reach the general subarachnoid space, but most of it enters the ventricles (Fig. 18b). Figure 18 demonstrates the change in direction of the air in response to varying degrees of flexion or extension of the neck.

That buoyancy plays the major part in determining the route taken by the air may be demonstrated in a series of experiments designed to vary the usual association of gravitational and postural influences. The patient lies in the prone position on a surface inclined at twenty degrees to the horizontal, the head being fully extended (Fig. 19a). The air rises into the dorsal part of the cervical subarachnoid space, enters the cisterna magna and passes into the ventricles (Fig. 19b). Thus, the ventricles are filled, although the posture of the head is the reverse of that usually adopted. Conversely, the patient lies with head flexed in the supine position with a similar inclination (Fig. 19c). In this posture the air tends to rise to the anterior part of the cervical theca and in spite of flexion of the neck it enters the cisterna pontis and is not seen in the cisterna magna (Fig. 19d). This is true whether the head is flexed or extended. The conditions of figure 19c may be more simply attained by directing the patient to lean backwards as he sits on the chair, his hands grasping the shelf usually employed as a support for the arms. In the light of these experiments it may be stated that, in the sitting posture, it is flexion of the neck and not of the head which is responsible for the entry of air into the cisterna magna. Actually only a small range of movement is possible at the atlanto-occipital articulations. These facts have been used in obtaining skiagrams of the fourth ventricle with only 5 c.cm. of air. The neck is flexed, but the nose and forehead are placed against the film, so that a direct postero-anterior view can be taken. This posture has not been used sufficiently often to justify comparison with the usual flexed position of the head and neck. The latter is more comfortable.

It may be thought possible that alteration of route in response to change in the position of the head might be due to postural widening of the space available in the foramen magnum anterior or posterior to the spinal cord. To obtain further evidence on this point a complete replacement was performed. Skiagrams were taken with the head in the usual flexed posture (Fig. 20a), erect (Fig. 20b), fully extended (Fig. 20c) and finally fully flexed (Fig. 20d). In all films air surrounding the spinal cord could be seen as anterior and posterior columns (the former obscured by the shadows of the condyloid and mastoid processes just below the foramen magnum). Full extension and flexion produced very little difference in these shadows. In flexion the antero-posterior diameter of the cistern was 1·4 cm.; in extension 1·3 cm.; and when the head was vertical, 1·4 cm. It may be stated, therefore, that the posture of the patient determines the distribution of the air solely by the fact that air tends to rise through water. By applying this knowledge air can be directed in any path with almost mechanical precision.

In the fourth ventricle the air is in a virtual "bubble-trap," displacing fluid as it rises. In the aqueduct of Sylvius the air probably ascends after the manner of a bubble rising upwards in a tube filled with water—surrounded by a column of fluid running downwards along the walls.

It has been suggested that pulsation of the brain determines the entry of air into the ventricular system. That this is not so is shown by the fact that filling occurs at least as rapidly in the properly-placed cadaver.

Failure of Ventricular Filling

Failure to fill the ventricles may be due to a number of causes. If the air is not introduced into the subarachnoid space it will not reach the ventricles. If the bevel of the needle is in, or partially in, the subdural space the air will separate the arachnoid and dura and will ascend into the cranial cavity. As soon as this is recognized, the error is rectified by reintroducing the needle into another intervertebral space.

In two patients, both suffering from epilepsy, attempts at encephalography were made during periods of headache following lumbar puncture. In the first patient the cerebrospinal fluid rose in the manometer only to the level of the fourth thoracic vertebra. Fifteen c.cm. of air were introduced but none appeared in the skiagrams. Possibly a further attempt in normal circumstances might have been successful, but unfortunately the patient's return to sea precluded this. In the other patient the fluid rose to the level of the sixth thoracic vertebra. Its pulsation appeared to be normal and it rose normally in response to jugular compression. Thirty c.cm. of air were introduced in quantities of 5 and 10 c.cm. at varying rates. It was noted that there was very little resistance to its introduction, and no rise of pressure resulted. On this account very little fluid was evacuated. No air appeared within the skull or upper cervical spine. Insertion of another needle and changing the syringe did not alter the findings. Skiagrams of the spine taken with the patient supine failed to reveal the location of the air. The simplest explanation was the presence of a leak in the introducing system, but none was found. At a second attempt ten days later the fluid in the manometer reached the level of the third cervical vertebra and the ventricles filled.

Thus failure occurred in two patients who were suffering from the typical headache which may follow lumbar puncture. This may be due to relative collapse of the arachnoid sac, causing difficulty in piercing the membrane, and to the presence of fluid outside its limits, even in the epidural region. This may have resulted from the first lumbar puncture, or less probably, at the time of the encephalography. It is therefore wise to wait for some days after the subsidence of a "post-lumbar puncture headache" before attempting encephalography. If the pressure is low and air does not enter the ventricles, it is probable that a second attempt at a later date will be successful. If, for any reason, air enters the subdural space it is best to resort to cisternal injection.

However, such errors of technique are not the only causes of failure, for this may occur when the air is introduced into the subarachnoid space. It is possible that arachnoidal adhesions may prevent the entry of air into the cisterna magna, but this is a rare cause of failure. If the foramen of Magendie be closed, as for example by fibrosis following meningitis, no air will enter the ventricles. The foramina of Luschka will allow the escape of cerebrospinal fluid, but they are so placed that they will not receive air.

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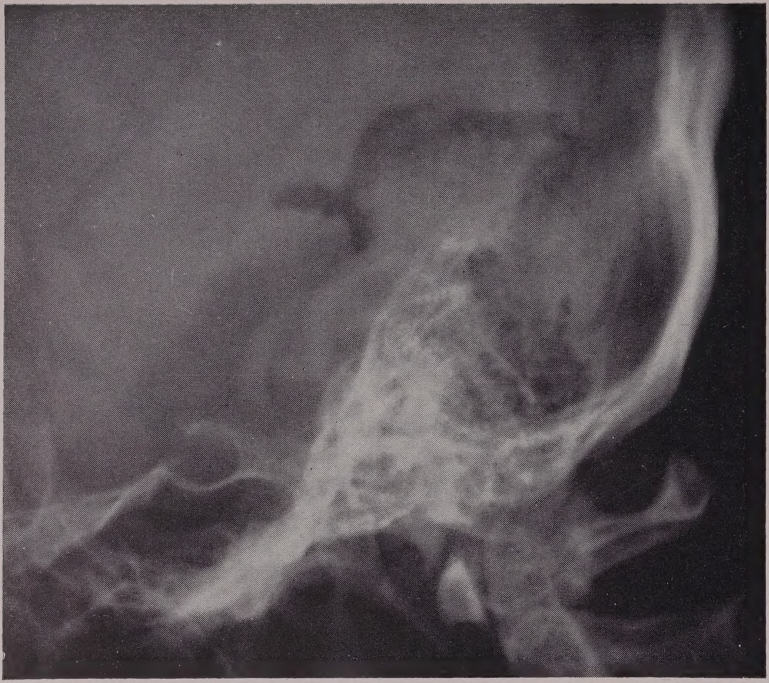
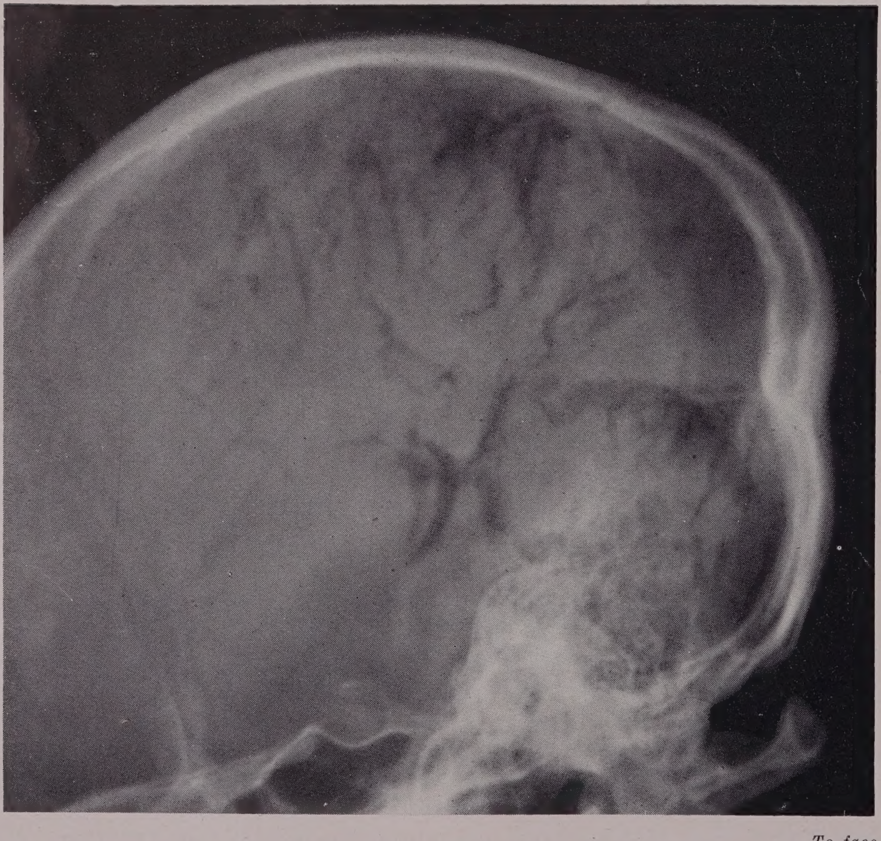


Fig. 21—An unusual distribution of air, due to communication between the cisterna magna and the remainder of the subarachnoid space over the cerebellum—(a) after the introduction of 7 c.cm., air is seen in the cisterna magna, over the superior surface of the cerebellum, and in the cisterna venae magnae cerebri. No air is seen in the basal cisterns, through which the air usually reaches the cisterna venae magnae cerebri; (b) after the introduction of 20 c.cm. the vermis is more completely outlined, and the air has extended upwards in the sulci over the occipital and parietal lobes.



Failure may occur when the foramen of Magendie is patent. In one patient (suffering from epilepsy) the air was able to escape from the cisterna magna by passing upwards around the vermis of the cerebellum to the cisterna venae magnae cerebri. After 5 c.cm. of air had been introduced at the rate of 1 c.cm. per minute a small accumulation was seen in the region of the cisterna magna. There was also a collection in an unusual position over the upper surface of the vermis of the cerebellum (Fig. 21a). Further injections of air increased the size and density of these shadows until the vermis of the cerebellum was very perfectly outlined (Fig. 21b). From the anterior and upper part of this shadow air extended forwards into the cisterna venae magnae cerebri. Thence, rising by the most vertical pathways available, the air outlined the sulci over the occipital and parietal lobes. Air entered the ventricles only when this part of the subarachnoid space was replete.

It is obvious that an unusual communication existed between the cisterna magna and the subarachnoid space over the remainder of the vermis, and as the defect is at a higher level than the passage into the fourth ventricle the air will escape through it. This condition probably represents the persistence of a state which usually disappears during development. In two other patients air was seen to follow this route, and in these instances it passed coincidentally into the ventricles. Two explanations are possible: firstly, some air passed directly into the anterior part of the cistern and thence through the foramen of Magendie. Secondly, although escape into the subarachnoid space over the cerebellum was possible, there was more resistance to the passage of air in this direction than in the case just described and a proportion passed into the ventricles.

The ventricular pathway may exert an unusual resistance to penetration. A brief analysis of the cases in which the ventricles were not outlined provides some evidence that failure is more likely to occur when there is a gross pathological lesion. In these cases useful information may be obtained from the filling of the cisterns and sulci which occurs.

One patient, a woman of forty-seven years, had an irregularly globular shell of calcification above the level of the sella turcica and to the left of the midline. The tumour was thought to be a craniopharyngioma extending in an unusual manner to one side of the skull, or possibly an aneurysm. The ventricles were not outlined. The cisterna chiasmatis did not fill with air and the anterior part of the interpeduncular cistern was encroached upon. No tumour was found at operation and the patient remains well.

The second patient suffered from severe headache and sensory Jacksonian epilepsy. There were many cells, including polymorphs, in the cerebrospinal fluid. Introduced air outlined only the subarachnoid space. The cisterna chiasmatis extended in a rather deep curve into an enlarged pituitary fossa, suggesting that the enlargement of the fossa was not due to an intrasellar tumour. Ventriculography revealed normal ventricles. Later, torulae were recognized in the cerebrospinal fluid. The patient died two years after the first investigation, and post-mortem examination revealed the typical findings of a torula meningitis. The foramen of Magendie was occluded by dense adhesions.

Five cubic centimetres of air were introduced into the theca of a patient who proved to have an aneurysm on the left middle cerebral artery in the stem of the Sylvian fissure, pressing into the brain in the region of the uncus. The air was seen in the right ambient cistern, but not in the left.

In the fourth patient, a middle-aged man, who suffered from headache and attacks which appeared to be of hysterical nature, the ventricles did not fill. The sulci appeared normal. Subsequent ventriculography revealed no definite abnormality. The clinical course over a period of three years has given no evidence of organic disease.

Another patient with symptoms suggesting dementia following a head injury, had wide sulci, but on two occasions no air entered the ventricles.

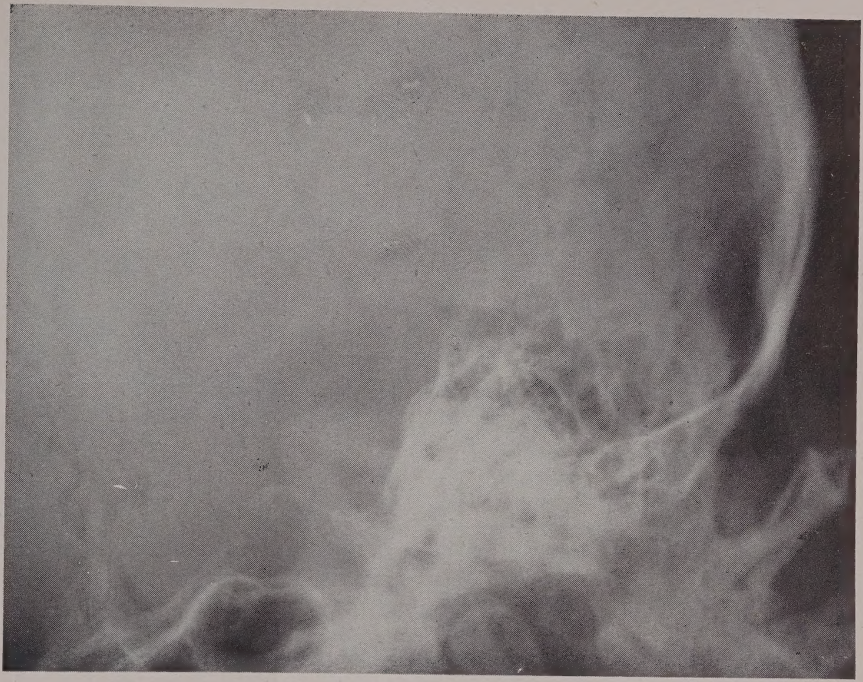
Subsequent to these failures a more determined effort was made to secure filling in every case. In the first such patient an attempt was being made to follow the pathway of air by taking lateral skiagrams during injection. Five c.cm. of fluid were removed and 10 c.cm. of air injected, at the rate of 2 c.cm. per minute. Half a minute after the commencement of the injection air was seen in the posterior part of the subarachnoid space below the level of the foramen magnum, and a small bubble had reached the upper limit of the cisterna magna. This accumulation enlarged until the posterior part of the cistern was filled. When 6 c.cm. had been introduced the shadow in the posterior subarachnoid space just below the foramen magnum began to increase in density. After 8 c.cm. had been introduced the shadow had a sharp lower border, which was horizontal. Some air had passed forwards and slightly upwards in a narrow band from the lower anterior part of this collection. During the introduction of the next 2 c.cm. this shadow increased in density. One minute after the termination of the injection the fourth ventricle was faintly outlined, but the air did not rise through the aqueduct. A similar picture was obtained four minutes later (Fig. 22a). The introduction of a further 10 c.cm. resulted in the appearance of air in the pontine, interpeduncular and chiasmatic cisterns, and a small amount of air was now seen in the third and lateral ventricles. During increased flexion of the head, jugular compression and the patient's straining a slight increase in the amount of air in the ventricles occurred, but the amount of air in the lateral ventricles was insufficient for radiography. The head was now slowly restored to the erect posture, and this resulted in a rapid increase in the amount of air in the ventricles (Fig. 22b).

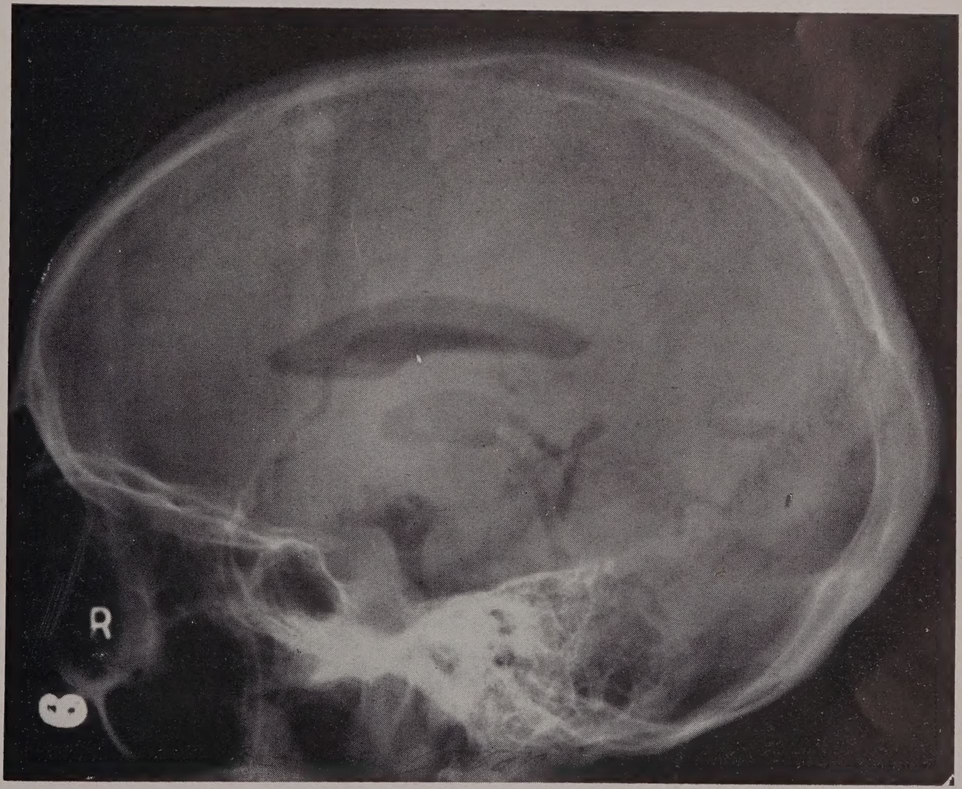
In a second case air penetrated the ventricles only very slowly and in small quantity from an accumulation over the posterior aspect of the spinal cord. Extreme flexion of the head and jugular compression had no effect in increasing the speed of ventricular filling; indeed, it appeared to cease. In the posture of extreme flexion the accumulation of air dorsal to the spinal cord extended as low as the fourth cervical vertebra. No air passed into the general subarachnoid space. After the head had been slowly restored from the flexed to the erect posture all the air introduced (20 c.cm.) passed into the ventricles and gave adequate pictures. The patient proved to have a meningioma growing from the region of the left pterion (Fig. 50).

In a third patient the cisterna magna was alone outlined after 10 c.cm. of air had been introduced. Slow extension of the head resulted in rapid ventricular filling. A repetition of this manoeuvre produced ventricular filling without escape of air into the general subarachnoid space. In none of these cases did the rapid transfer of air into the ventricles produce headache.

In some cases it appears that the air accumulates in the large posterior part of the cisterna magna, which is at a higher level than that part leading to the ventricle, and does not coincidentally pass through the anterior part into the fourth ventricle. By bringing the head into the erect posture, and by further extension, the posterior part of the cistern is brought to a lower level and the air is poured into the fourth ventricle. In rare instances, in spite of flexion of the head and neck, the air passes into the general subarach-

Fig. 22—An attempt to obtain ventricular filling in a difficult case—(a) film taken five minutes after 10 c.cm. of air had been slowly injected. The air outlines the cisterna magna and passes forwards into the fourth ventricle which is faintly outlined; (b) ventricular filling rapidly following extension of the head and neck thirty-five minutes later. During part of this time the head and neck were fully flexed, and more air was introduced.





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noid space at the same time as, and in greater quantity than, it enters the ventricular system. In one such case air showed in the ambient cisterns after the introduction of 5 c.cm. After 20 c.cm. had been introduced only a very faint shadow, insufficient for accurate skiagrams, was seen in the ventricles. It was decided to attempt to fill the ventricle by supplying a larger quantity of air during a longer period. After 80 c.cm. of air had been introduced the ventricles were adequately filled, although most of the air had reached the subarachnoid cisterns and sulci. The rapid filling of the general subarachnoid space in such cases may be due to a relative block of the subarachnoid space dorsal to the cervical spinal cord, to an easily-penetrated communication between the upper part of the cisterna magna and the subarachnoid space ventral to the medulla, or to slow transfer of air into or through the ventricular system. If the passage through the aqueduct of Sylvius were impeded air might escape from the fourth ventricle through the foramina of Luschka. In the case described the cisterna magna contained air, suggesting that there was no block below it. The influence of the intracranial pressure upon ventricular filling has not been adequately investigated. A high pressure, due to neoplasm, may cause compression of the cisterna magna and in extreme cases impaction of the cerebellar tonsils in the foramen magnum. The neoplasm itself may cause a mechanical blockage of the ventricular pathway. Nevertheless, certain experiences have given the impression that a moderate increase of intracranial pressure may favour ventricular filling and, conversely, a low pressure tends to prevent it. In a case in which air was passing very slowly into the ventricles the rate appeared to be increased by various manoeuvres which increased the intracranial pressure—excessive flexion of the neck, jugular compression, and abdominal straining. However, adequate control of the influence of time alone was not made. Jugular compression maintained during the introduction of air does not prevent entry into the ventricles. In another patient, displacement bottles were being used to introduce air. (A syringe is usually used because it is a simpler and surer method of introducing air.) Fifteen c.cm. of fluid was inadvertently evacuated before air was introduced. When the leak was rectified air entered the subarachnoid cisterns and sulci rather slowly, and the ventricles were not seen. At a subsequent attempt under the usual conditions the ventricles were filled. In two cases with low pressures consequent upon lumbar puncture air did not enter the ventricles, but this was probably due to a failure to introduce air into the subarachnoid space. These problems demand investigation in the suitable cases which arise from time to time.

The manoeuvres to secure ventricular filling will not succeed in every case. In one patient, suffering from epilepsy, no air could be induced to enter the fourth ventricle whatever the posture of the head, although the cisterna magna was well filled. This case is the seventh in the group in which ventricular filling was not obtained. The cause may have been blockage of the foramen of Magendie.

These results have been described, because they provide a basis for further observations upon suitable cases and because their study has led to better technical results. The following points have emerged:

(i) It is better not to attempt encephalography until some days after the subsidence of a "post-lumbar puncture headache."

(ii) In the initial stages it is wise to employ about twenty-five degrees of flexion of the head and neck. A certain degree of flexion of the neck is necessary to cause all the air to enter the cisterna magna. The greater the degree of flexion the less likely is air to escape anterior to the medulla, but it may accumulate in the cisterna magna rather than pass into the ventricles.

(iii) If the air is seen in a capacious cisterna magna in the first film, the ventricles will probably fill after the posterior part of the cistern is replete. Air will pass into the ventricles at an earlier stage if the head is dorsi-flexed after each injection of air.

(iv) If, after the first introduction, air is seen only in the ambient cisterns, the neck is fully flexed and, after each injection, fully dorsi-flexed. This is an important manoeuvre in determining filling in such cases, which are not infrequent.

(v) If, in the flexed posture, air enters the basal cisterns rapidly and the ventricles more slowly, an adequate ventricular filling may be obtained by slowly introducing a large quantity of air. If this state of affairs exists with the semi-flexed posture, the use of the procedure described above will probably prevent the flow into the basal cisterns, and so hasten filling of the ventricles.

(vi) If the air escapes from the cisterna magna over the dorsum of the vermis and does not coincidentally enter the ventricles, the ventricles may fill after the dorsally-situated subarachnoid spaces are replete.

To summarize, two physical factors appear to favour the entry of air into the ventricular system:

Firstly, buoyancy plays the largest part in determining the course of the air. Ventricular filling is secured by posing the patient, so that the air rises into the cisterna magna, particularly its anterior part. When the patient is sitting, a flexed posture of the neck is necessary. If there is too small a degree of flexion some air is likely to pass anteriorly into the basal cisterns. Filling of almost any part of the intra- and peri-cerebral spaces can be effected by the utilization of this gravitational effect.

Secondly, the slow introduction of air is an important factor in determining a clear-cut ventricular filling; for if air is introduced more rapidly than it can pass into the fourth ventricle, it will overflow from the cisterna magna into the general subarachnoid space.

Chapter V

THE FOURTH VENTRICLE

In a number of publications Lysholm has described a manoeuvre for filling the fourth ventricle with air from that already in the ventricles; but this and attempts with other postures have given very inconstant results during encephalography in the writer's hands. These methods give more satisfactory results when large quantities of air have been introduced by ventricular puncture, and particularly when the ventricles are dilated. Twining (1939) has reviewed the methods used to outline the fourth ventricle with air already in the lateral ventricles, including postures of his own devising.

In the course of a valuable contribution published after his untimely decease, Twining (1939, a) states:

> Encephalography by the lumbar route will sometimes show the third ventricle, the aqueduct, and the fourth ventricle, as well as the basal cisternae, but the method is somewhat uncertain; it is impossible to know beforehand whether the air will pass mainly along the cisternal route to the cerebral sulci or take the alternative route through the foramen of Magendie into the cerebral ventricles. Often it takes both routes and the air in the sulci, basal cisterns (cisterna interpeduncularis and cisterna chiasmatis) together with the air in the subarachnoid spaces in the region of the Sylvian fissure overlap and obscure the image of the third ventricle. Furthermore, the method is to be used with great caution where tumour is suspected, since withdrawal of any considerable amount of cerebrospinal fluid may lead to herniation of the cerebellum into the foramen magnum or of the temporal lobe into the incisura tentorii.

It is not possible to concur in the first part of this statement for it usually possible to fill the ventricles alone by the technique described, and adequate pictures of the third and fourth ventricles are obtained in all but a small percentage of cases. The author is, however, in complete agreement with the latter part of Twining's statement. Both ventriculography and encephalography have special spheres of usefulness, and the choice depends chiefly upon the presence or absence of increased intracranial pressure. The use of encephalography is limited, but the facility with which it may be employed makes it a valuable addition to the methods available for the early diagnosis of the intracranial lesions, including those in the posterior fossa.

Hyndman (1938), in an important contribution, describes the combined use of ventricular and spinal injection of air to secure adequate skiagrams of the third and fourth ventricles and the aqueduct of Sylvius:

> If air does or does not communicate between the two lateral ventricles and the injection has been complete enough to give good visualization of both ventricles on the same roentgenogram in the lateral positions, but without visualization of the third ventricle, there exists obstruction of both foramina of Monro or of the third ventricle itself. It is in such a case that a supplementary spinal injection of air in selected cases may outline the distal margin of a tumour and thus guide the surgeon in his important choice of exposure.

He advocates complete replacement, stating that the method is attended by no danger if any excessive intracranial pressure has been relieved.

Actually it may be claimed that satisfactory visualization of the fourth ventricle is obtained more easily and more regularly when the air is entering the ventricular system than when it is leaving.

Anatomy

The appearance of the fourth ventricle in encephalograms depends upon certain anatomical facts calling for description. The fourth ventricle is situated under cover of the cerebellum and upon the dorsal aspect of the pons and upper part of the medulla (Fig. 23). From the upper angle the aqueduct of Sylvius extends upwards under cover to the quadrigeminal plate to the postero-inferior angle of the third ventricle. At its lower angle the cavity is continuous with the central canal of the spinal cord. The floor of the ventricle is rhomboidal in shape, resembling an inverted kite. The striae medullares crossing the floor from the acoustic tubercles (elevations produced by the dorsal cochlear nucleus on each side) divide the floor into a long upper part, posterior to the pons, and the short lower part, posterior to the medulla.

Ventral to the fourth ventricle are the nuclei of the fifth, sixth, seventh, eighth, ninth, tenth and twelfth cranial nerves in whole or in part. The sensory nuclei and the seventh and twelfth nuclei are most intimately related to the floor of the ventricle. These two motor nuclei cause expansions of the median eminence on each side, termed the colliculus facialis and the trigonum hypoglossi. The median eminences on each side are separated by the median sulcus in the midline. Little of this is of practical importance in the interpretation of encephalograms, as these structions cannot be defined. From the lateral angles, the lateral recesses (Fig. 24) extend outwards and forwards around the inferior cerebellar peduncles, to reach the cerebello-pontine angle on each side in fairly close relationship to the floccules, and the seventh, eighth, ninth and tenth cranial nerves.

The lateral boundaries of the ventricle are narrow, and are formed by the superior and inferior cerebellar peduncles, to which are attached the roof of the ventricle. The anterior and posterior medullary vela and the tela choroidea inferior are the component parts of the roof (Fig. 23). The two medullary vela issue from the same point in the medullary body of the cerebellum and diverge at an acute angle. The anterior medullary velum is a layer of white matter which stretches between the two superior cerebellar peduncles. It emerges from the cerebellum and merges cranially into the quadrigeminal plate. The posterior medullary velum is a nervous structure which runs between the peduncles of the floccules, and its medial part passes downwards and forwards over the nodule of the vermis of the cerebellum. To its well-defined lower crescentic border is attached the tela choroidea of the fourth ventricle, which roofs the inferior part of the ventricle and is composed of ependyma supported by pia mater. It is attached on each side to the inferior cerebellar peduncle, crossing the posterior surface to gain its medial border, and then passing on at a lower level to be attached to the medial part of the clava. Posterior to it are, in the midline, the tonsils of the cerebellum meeting in front of the uvula (Fig. 24), or the uvula of the vermis (Fig. 26), (for there is considerable anatomical variation in the distance of the uvula from the floor of the fourth ventricle). Laterally lie

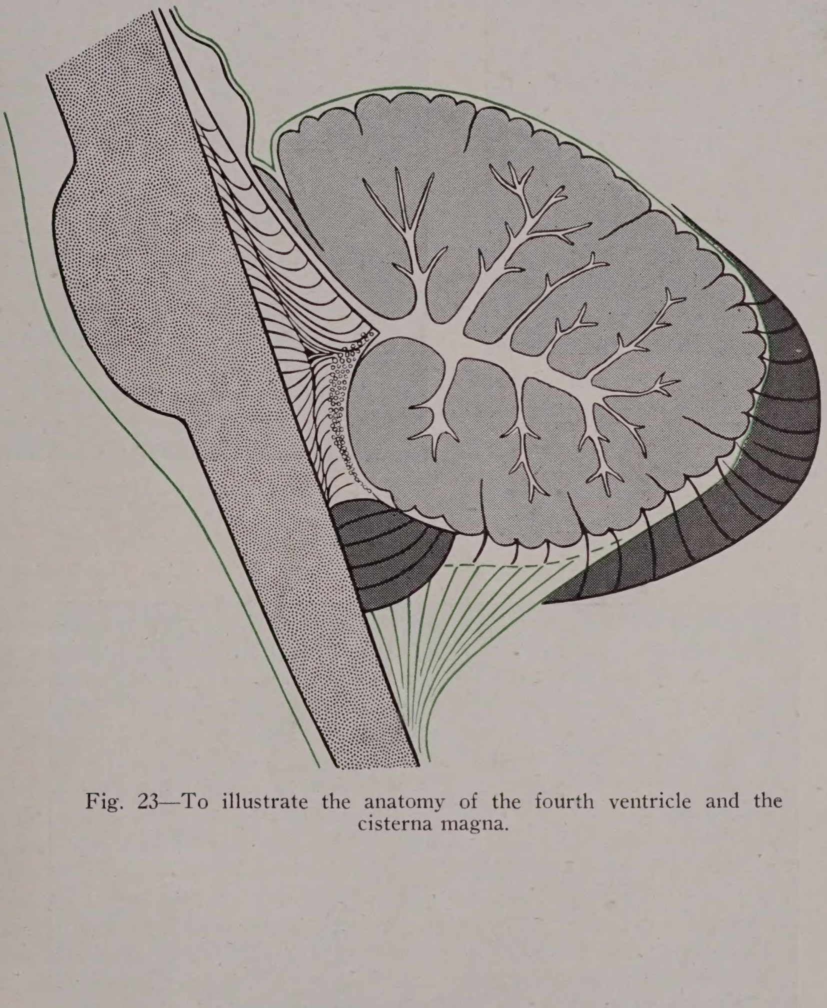

Fig. 23—To illustrate the anatomy of the fourth ventricle and the cisterna magna.

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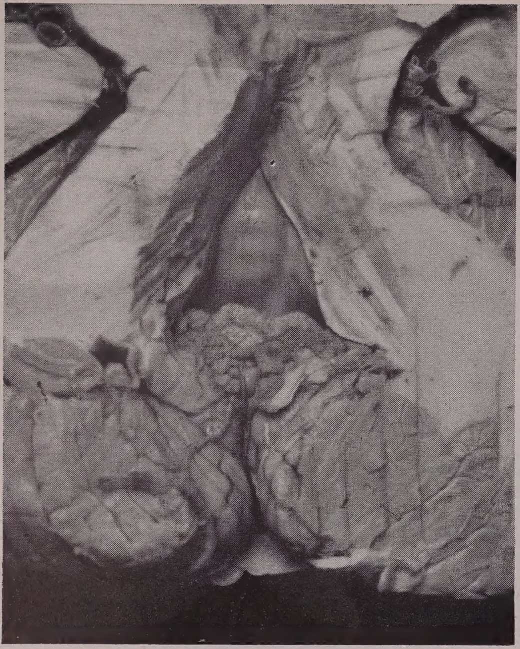

Fig. 24—A dissection exposing the roof of the fourth ventricle and the choroid plexus. The deep part of the cisterna magna between the tonsils of the cerebellum, in which air ascends to enter the ventricle, is demonstrated.

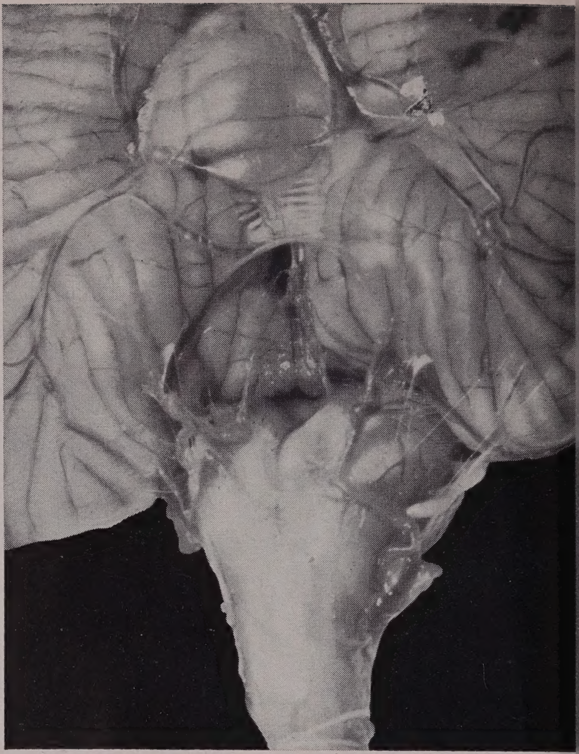

Fig. 25—The foramen of Magendie exposed by pulling the medulla forwards.

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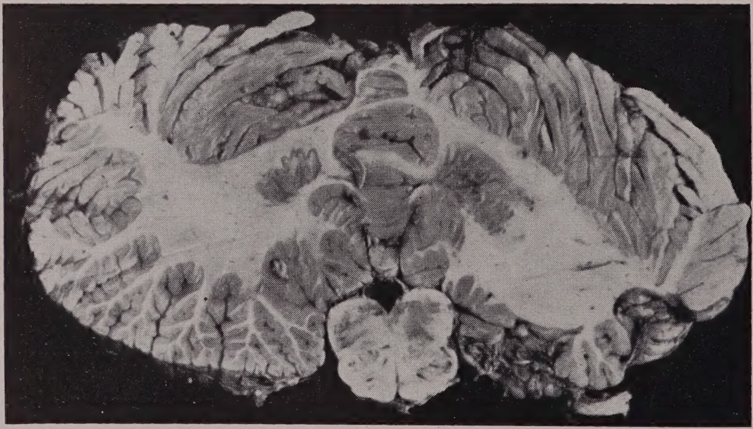

Fig. 26—Transverse section of the medulla and cerebellum at the level of the foramen of Magendie. In this specimen the tela choroidea of the fourth ventricle overlies the uvula, with the tonsils on each side.

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the medial and upper parts of the tonsils of the cerebellum. In the course of development the tela is a continuous sheet, but later it becomes fenestrated in three places, forming the single median foramen of Magendie below (Fig. 25), and the paired foramina of Luschka at the extremity of each lateral recess. The foramen of Magendie opens into the upper prolongation of the cisterna magna as it lies between the medulla in front and the uvula and tonsils posteriorly and laterally. The anterior wall of the foramen of Magendie is formed by the medulla, into which is incorporated the obex—the portion of the tela chloroidea forming the anterior lip of the foramen. As seen from below the opening usually faces forwards as well as downwards. The foramina of Luschka are situated at the apices of the lateral recesses of the ventricle so that they open into the lateral recesses of the cisterna pontis, in the cerebello-pontine angles. The pia mater forming the roof of the inferior part of the ventricle is continued below the foramen of Magendie, as is shown in Figure 25. At the level of the foramen the ciliated cuboidal ependymal cells disappear and, below, only the flattened type of cell characteristic of the pia mater is seen. Eventually the sheet splits into a number of interlacing trabeculae which spread over the neighbouring parts of the tonsils and merge into the pia mater. Sometimes definite strands run as far back as the pyramid of the vermis. These, in conjunction with fine strands running from the posterior aspect of the tela to the vermis and tonsils, keep the tela in contact with these cerebellar structures. The close apposition of the tela and the cerebellar substance above the foramen limits the upward extent of the cisterna magna.

The ependyma lining the tela choroidea is continuous with that lining the remainder of the roof and the floor of the ventricle. The tela is supported externally by pia mater, vascular tufts from which invaginate its ependyma, thus constituting the choroid plexus (Fig. 23 and 24). There are horizontal and paired vertical lines of invagination. The vertical lines commence immediately above the foramen of Magendie and run upwards on each side, covering parts of the tonsils and nodule. Above each vertical limb turns laterally, over the upper part of the tonsil and the peduncle of the floccule. Laterally each joins with the horizontal limb and expands through the foramen of Luschka to project into the cerebello-pontine angle below the floccule. The horizontal limb is continuous across the midline, lying on the nodule of the vermis, posterior to the remainder of the plexus. A continuation of the vertical limbs below the foramen of Magendie may be seen on the pial band described above (Fig. 25). Inside the ventricle the vertical limb on each side, overlying the projection formed by the tonsils and the nodule, may thus reduce the antero-posterior depth of the body of fluid filling the lateral portions of the lower part of the ventricle. A deep but narrow median cleft is then formed. As the air rises above fluid the shadow seen during filling in postero-anterior views with the head flexed depends upon the projection of component parts of the roof rather than upon the floor. It is probable that in life the effect is accentuated by greater projection of the choroid plexuses. The presence of a well-marked dorsal median groove provides a satisfactory explanation of the appearances seen in encephalograms.

Appearances in Skiagrams

Air enters the aqueduct of Sylvius and the third ventricle with surprising rapidity. In one patient air was introduced at the rate of 2 c.cm. per minute

(Fig. 27). At the end of a minute, a narrow column of air was to be seen in the midline of the skull, extending upwards from the region of the foramen magnum (Fig. 27a). At the end of two minutes a rounded shadow, thrown by air in the fourth ventricle, was added at the upper end of the narrow shadow (Fig. 27b). Above this a faint shadow tapered into a short, narrow column, densest cranially. This represented air in the aqueduct of Sylvius. A wider shadow above this, resembling an elongated oval, was thrown by air in the posterior part of the third ventricle. At the end of three minutes (after the injection of 6 c.cm.) the shadow representing the third ventricle was a little denser and more elongated, due to filling of its anterior part. As will be shown later flexion of the head brings the shadow of this part of the ventricle to a low level, overlapping the shadow of the fourth ventricle. Air was now appearing in the right lateral ventricle (Fig. 27c). The fourth film taken one half-minute after the termination of the injection (7 c.cm. in all), showed air in both lateral ventricles (Fig. 27d).

The rapidity of transit of air is variable. After 5 c.cm. have been introduced the air is commonly seen in lateral views in the cisterna magna as well as in the third and fourth ventricles. Occasionally, however, in the earlier films the air may be seen in the cistern only, although ventricular filling occurs later. Skiagrams, taken at intervals during filling, show that air usually enters the posterior part of the cistern before or while it passes through its anterior part to the fourth ventricle. Sometimes the passage of air is very rapid. In one patient 6 c.cm. of air were injected in two minutes and four skiagrams were taken at intervals of one minute. In the first film the fourth ventricle, the aqueduct, and the third ventricle were revealed. At the end of two minutes (by which time injection was complete) the third ventricle was more densely defined and air had entered the right lateral ventricle. A little more air was seen in the third film, but the fourth showed no increase. The shadow of the fourth ventricle was present in the first two films and absent in the two films taken one and two minutes after the introduction was completed. Later films showed that the lateral ventricles were dilated, and it has been found that when this obtains the air passes very rapidly through the lower ventricles.

The rate of transit through the ventricles was estimated when the air was injected directly into the cisterna magna. Five c.cm. of air was injected at the rate of 1 c.cm. per minute. Lateral films were taken at frequent intervals. At the end of one half minute air was seen in the dorsal and upper part of the cistern which, in this case, was not very capacious. Half a minute later the shadow in the cistern was darker and air was seen in the posterior part of the fourth ventricle. A minute later, the fourth ventricle and aqueduct were clearly outlined, and the dorsal part of the third ventricle could be seen. At the end of another minute the shadow of the third ventricle had extended forwards and air was seen in one lateral ventricle. At the end of the injection the shadow in the lateral ventricle was larger. This continued to increase slightly in size over the next three minutes, although at the end of this time the third and fourth ventricles could still be faintly discerned. The shadow of the dorsal part of the cistern remained unaltered throughout.

In another patient with normal ventricles air was injected into the cistern more rapidly—5 c.cm. in one minute. Films were taken at intervals of half a minute. The first film (taken after 2½ c.cm. had been injected)

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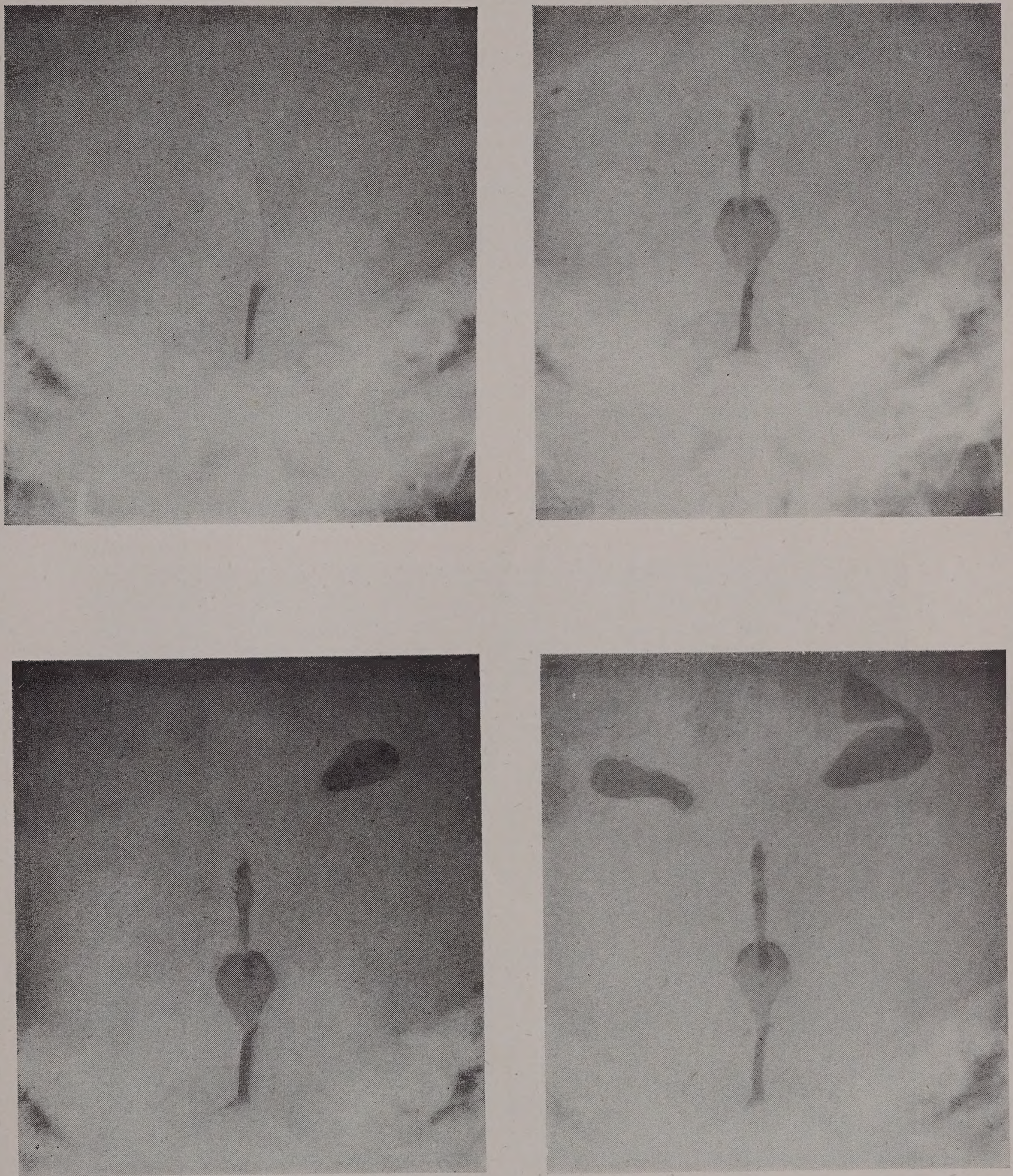

Fig. 27—Postero-anterior skiagrams, taken at intervals of one minute, with the head flexed, to demonstrate the passage of 7 c.cm. of air injected at the rate of 2 c.cm. per minute.

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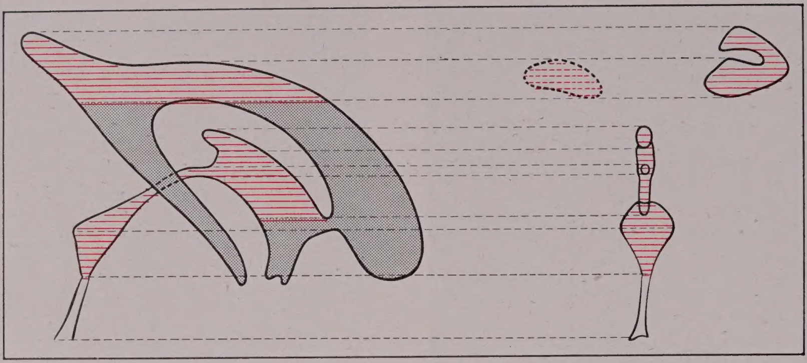

Fig. 28—Diagram to illustrate the appearances in postero-anterior skiagrams taken during filling with head in the semi-flexed position (red, air in the ventricles; black stipple, residual fluid). The film analysed is shown in Fig. 27d.

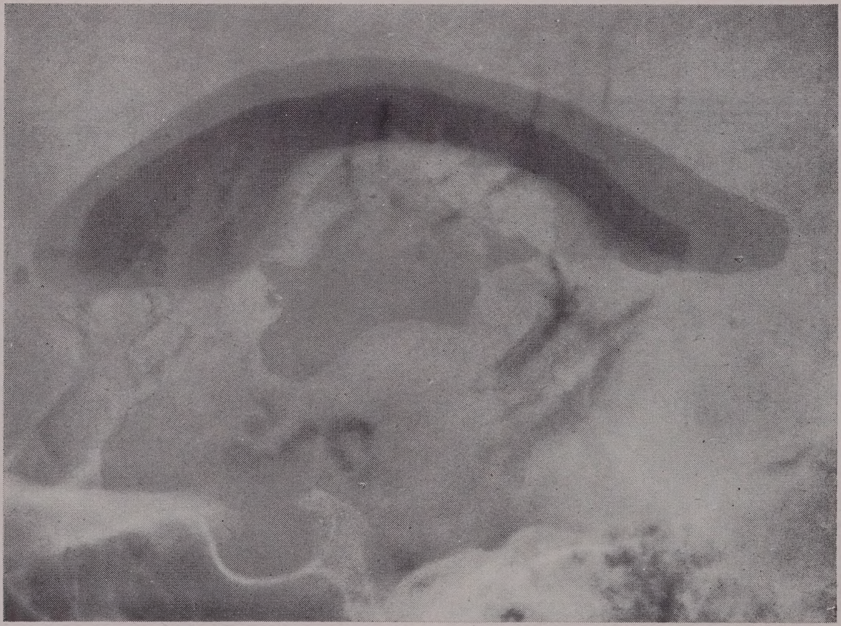

Fig. 29—Showing the extensive downward filling of the third ventricle which is sometimes seen in skiagrams taken with the head erect.

showed air in the cisterna magna, in the fourth ventricle, aqueduct of Sylvius and dorsal part of the third ventricle. The second film showed a denser and larger shadow in the third ventricle and in addition air in one lateral ventricle. The third film (taken half minute after the end of the injection) showed air loculated in the upper and dorsal part of the cisterna magna. The shadow of the fourth and third ventricles was fainter and that in the lateral ventricles was larger. In the fourth film no air was seen in the two median ventricles. The shadow in the cistern was unchanged and that in the lateral ventricle was larger.

An attempt has been made to follow the course of the air under the fluorescent screen. It was found difficult to detect other than moderately large accumulations of air. The early stages of change from fluid-filling to air-filling, which it was hoped to observe, were not discernible. The cisterna magna was clearly outlined, and the lateral ventricles were quite translucent, but the third and fourth ventricles were not easily seen. Undoubtedly, with practice, the method could be used, but it is difficult for one person to perform the lumbar puncture, introduce the air, and observe the screen. Without permanent records of the faint shadows of the third and fourth ventricles important details might escape observation.

When the postero-anterior skiagrams are taken with the head flexed and with a slight upward inclination of the centre-ray, the shadows have a characteristic appearance (Figs. 3b and 27) quite different from that when the head is erect (Figs. 4a, 30 and 36). The inclination throws the shadow of the fourth ventricle clear of the dense opacities produced by the base of the skull. A narrow shadow rises from the foramen magnum to the fourth ventricle. This is caused by air in the narrow passage posterior to the medulla between the cerebellar tonsils. As previously described this represents part of the cisterna magna below the level of the foramen of Magendie, and part of the fourth ventricle above that level. The air ascends in the highest available position, that is, in the groove between the two vertical limbs of the choroid plexus. Above the nodule of the vermis the air spreads out below the triangular roof of the ventricle (Figs. 23 and 24). In the flexed posture of the head, when the centre ray is directed upwards at five degrees it approximates to the line of the roof of the fourth ventricle (Fig. 28), which appears as an arc of a circle (Fig. 27), the shadow being densest above. From the upper part of this shadow the narrow aqueduct of Sylvius extends upwards in the middle line. The line of the centre-ray almost coincides with the axis of the upper part of the aqueduct, so that the latter appears as a dark, circular shadow at the upper end of the lighter shadow of the remainder of the aqueduct. A larger circular shadow, which is seen above this, is cast by the posterior part of the third ventricle (the suprapineal recess). The anterior part of the third ventricle throws a long, narrow shadow, the lowest part of which may be superimposed upon the shadow of the fourth ventricle. *A priori,* it would be thought that the air in the third ventricle would not replace fluid below its point of entrance. However, in lateral views, the fluid level is often considerably lower than this (Fig. 29). It is possible that vascular pulsation may squeeze fluid from this very narrow part of the ventricle.

If a skiagram is taken with the head erect, the forehead and nose being against the cassette, the triangular shape of the upper part of the ventricle is seen (Fig. 30). The two lateral recesses may be outlined as they pass laterally from the lower angles of the triangle to the foramina of Luschka. Sometimes the lower part of the ventricle appears as a smaller triangle with its base uppermost (Fig. 31), but often the air in the inferior part appears as a narrow column (Fig. 34b), continuous through the foramen of Magendie with the column in the cisterna magna. In this projection the shadows of the clinoid processes approach the lower part of the shadow of the fourth ventricle. The lateral recesses of the fourth ventricle (Figs. 34b and 36) are more often seen in films taken in the nose-forehead posture, than in the early flexed position. This probably depends upon the stage at which the films are taken, there being more air present when the nose-forehead film is taken. The shadow of the aqueduct is longer in this projection and that of the third ventricle is shorter (Fig. 32). The fluid level in the third ventricle is projected higher, roughly corresponding with the upper end of the aqueduct. It is important to realize that apparent lateral displacement of the shadow of the fourth ventricle may be produced by a slight error in posturing. The influence of rotation of the skull is shown in Figure 33 where the effect was deliberately produced.

In lateral views the rounded projection of the nodule of the vermis, covered with choroid plexus, produces the characteristic concave border of the postero-inferior part of the shadow (Figs. 34a and 35). This projection may extend almost to the floor of the ventricle. The lower part of the ventricle may be represented by a triangular shadow with its acute angle directed downwards and slightly backwards (Figs. 7b and 34a). This represents, in lateral views, the channel between the choroid plexuses referred to above, deep in its postero-anterior direction but narrow from side to side. Air may sometimes be clearly seen in the passage between the fourth ventricle and the posterior part of the cisterna magna (Fig. 49a). In cases of cerebellar atrophy this channel may be wide in the antero-posterior direction (nine millimetres in one patient). No constriction could be seen corresponding to the position of the foramen of Magendie.

Measurements

Measurements were made in forty patients in whom there was no evidence of abnormality in the posterior cranial fossa. An analysis of these may serve as an index of the normal. In lateral films the shortest distance between the dorsum sellae and the aqueduct of Sylvius is a measure of the space occupied by the cisterna pontis and the pons; and after filling the cisterna pontis the antero-posterior depth of the pons itself may be accurately measured. If there is any suspicion of a pathological lesion in this region an attempt is made to outline the aqueduct and the cisterna pontis. In routine investigations the cisterna pontis was not always filled so the distance between the dorsum sellae and the aqueduct is cited below. Increase in this measurement must be due to pontine expansion or to a space-filling lesion in front of the pons. The latter is the less likely cause. In a series of forty cases the distance between the dorsum sellae and the aqueduct varied between 3 and 4 cms. The distribution is shown in table I.

The most constant and easily measured diameter of the fourth ventricle is the shortest line from the point of junction of the anterior and posterior medullary vela to the floor. In normal subjects this varied between 1·3 and 2·1 cms., more than half falling between 1·5 and 1·8 cms. In two patients, one with stenosis of the aqueduct of Sylvius and the other with a

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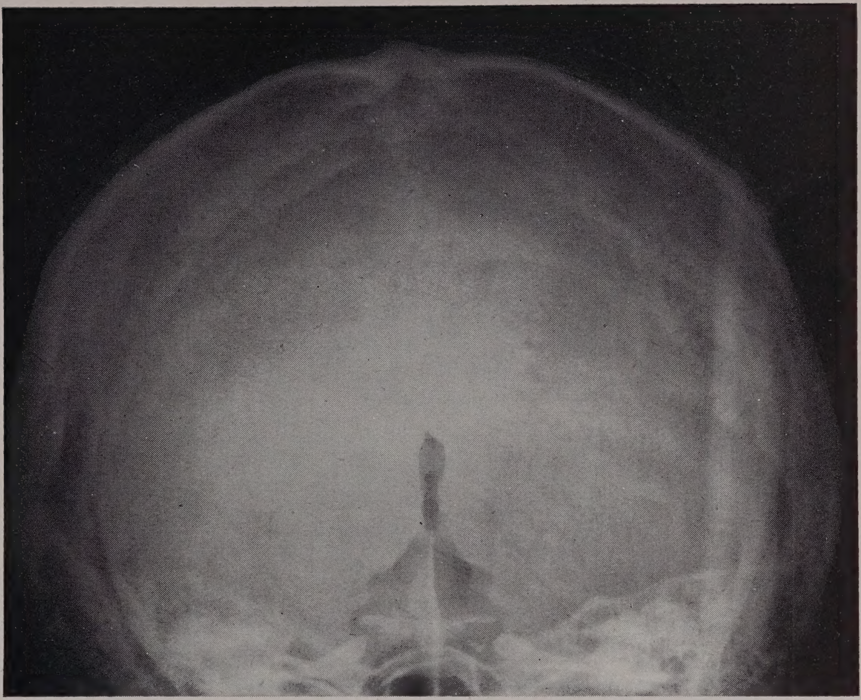

Fig. 30—The fourth ventricle, aqueduct of Sylvius and third ventricle as seen in a postero-anterior skiagram with the forehead and nose against the film, after the introduction of 6 c.cm. of air.

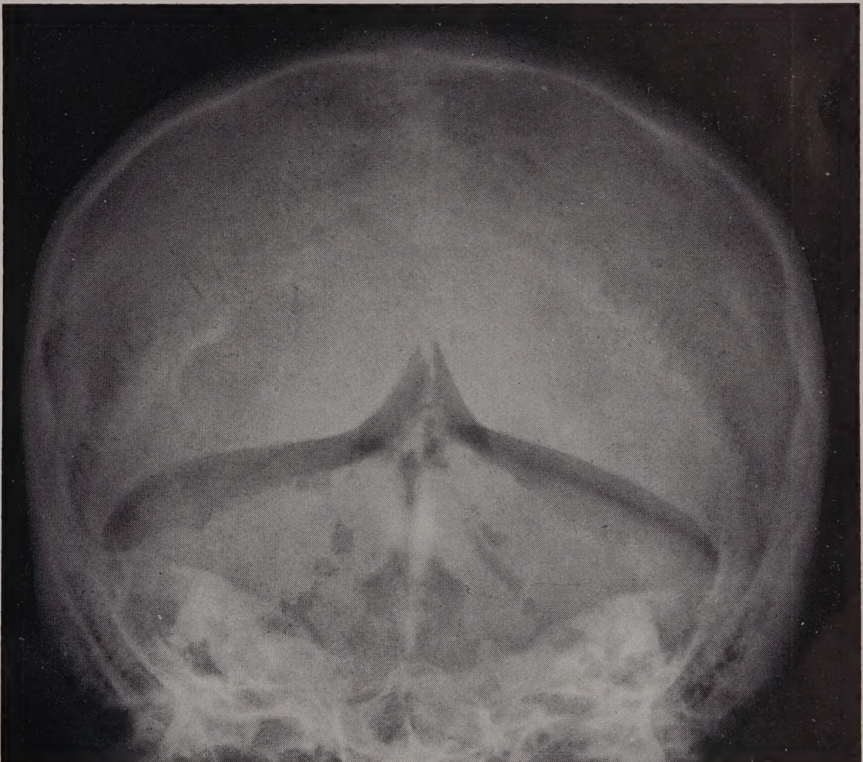

Fig. 31—Filling of the lower part of the fourth ventricle. Air is seen collected under the tentorium, and also in the ambient cisterns

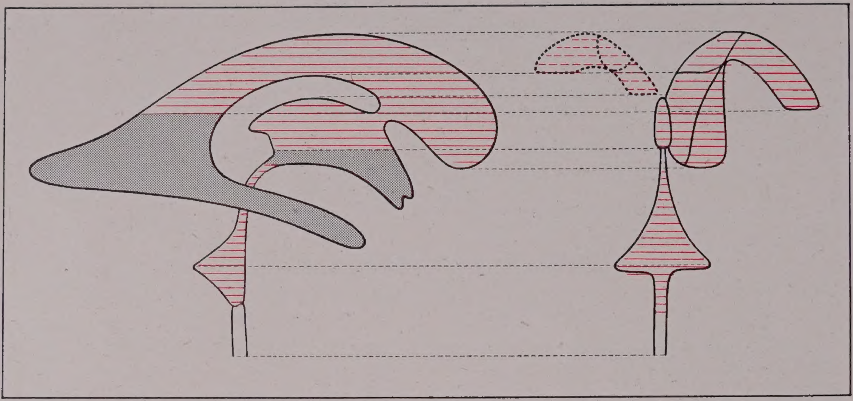

Fig. 32—The appearances seen in postero - anterior films taken with the head erect—for comparison with Fig. 28. The film analysed is shown in Fig. 4b (red, air in ventricles; black stipple, residual fluid).

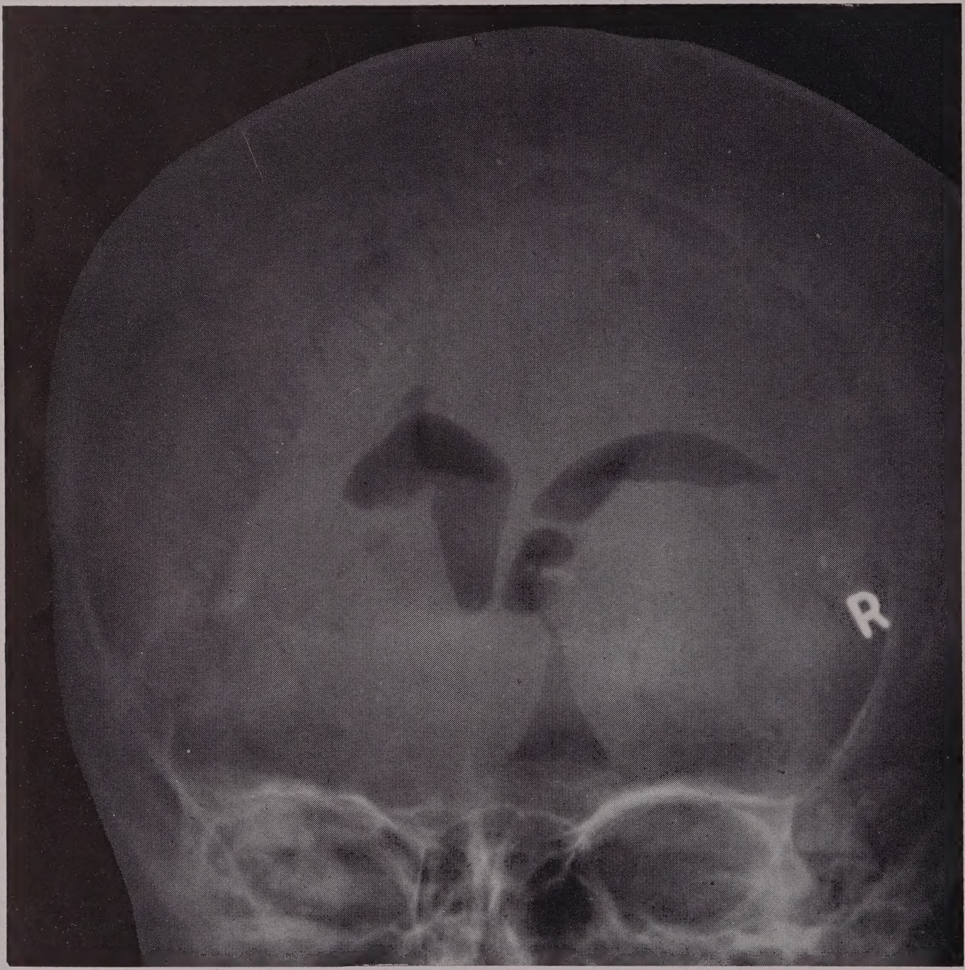

Fig. 33—The effect of rotation upon the position of the ventricular shadows. The right mastoid process was nearer the film than the left (postero-anterior view).

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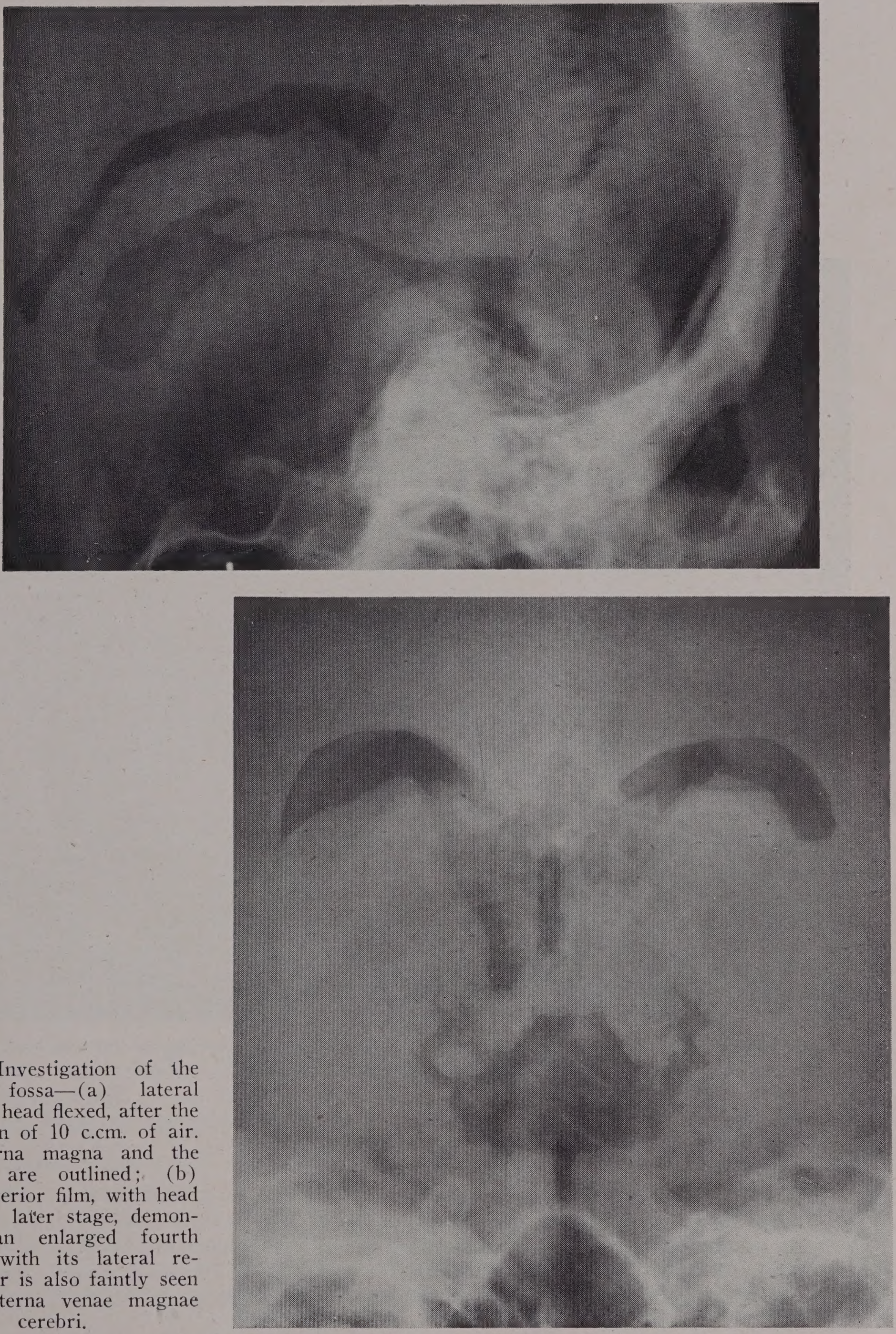

Fig. 34—Investigation of the posterior fossa—(a) lateral view, with head flexed, after the introduction of 10 c.cm. of air. The cisterna magna and the ventricles are outlined; (b) postero-anterior film, with head erect, at a later stage, demonstrating an enlarged fourth ventricle, with its lateral recesses. Air is also faintly seen in the cisterna venae magnae cerebri.

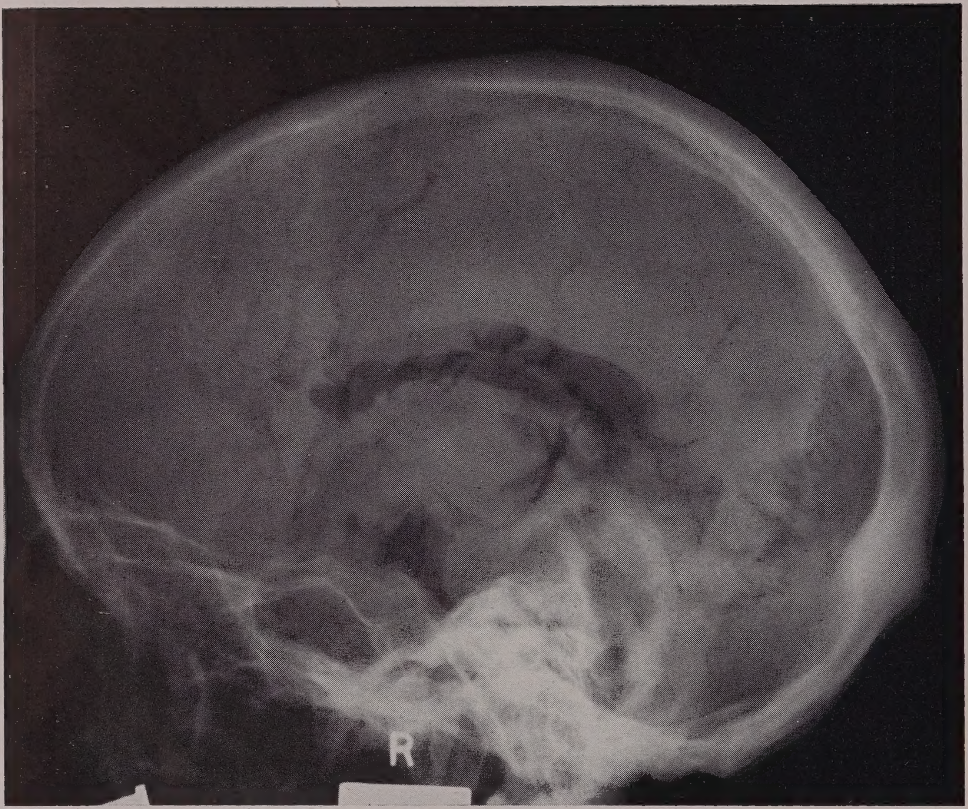

Fig. 34c—Lateral film after the cisterns had been filled. The outlines of the pons and quadrigeminal plate are seen.

parasagittal meningioma, without increased intracranial pressure, this diameter was 1·1 cms. In a case of cortical cerebellar atrophy the diameter was 2·8 c.ms. In a patient with hydrocephalus due to obstruction of absorption of the cerebrospinal fluid the diameter reached 2·7 cms.

Estimation of the width of the ventricle is much more difficult, because of the inconstant filling of the lateral recesses. The most constantly available dimension is the width of the shadow of the ventricle proper at the upper level of the lateral recesses, that is, between the points where the lateral walls commence to diverge more markedly. The ventricle expands below this level, and, although the maximum width can sometimes be estimated, it is not as constantly available as the measurement described above. Because of the difficulty of fixing these boundaries with accuracy, measurement of the lateral diameter of the ventricle is much less satisfactory than that in the antero-posterior direction. In normal cases the width of the ventricle just above the lateral recesses varied between 1·3 cms. and 2 cms. In a patient with olivo-ponto-cerebellar degeneration it measured 2·4 cms.

TABLE 1

Distance between the dorsum sellae and the aqueduct

Distance in cm.	*No. of Cases*
3	3
3·1	3
3·2	6
3·3	1
3·4	6
3·5	7
3·6	4
3·7	1
3·8	2
3·9	2
4	5

When the vermis of the cerebellum is outlined above and behind by subarachnoid air, and in front, by air in the fourth ventricle (Fig. 62) its size can be estimated. This may be useful in cases of cerebellar atrophy. The lower part of the vermis may be seen between the inferior part of the fourth ventricle and the cisterna magna (Fig. 34a). The lateral extensions of the cisterna magna, however, may obscure its central part and prevent accurate measurement (Figs. 34a and 41). The diameter of the vermis is variable. Only a very large series of measurements might prove useful as an indication of the normal limits.

Illustrative Cases

P.R., a man of forty-seven years had suffered for twelve months from pain of neuralgic character referred to the first and second divisions of the left trigeminal nerve. Sometimes the pain extended behind the ear, and occasionally as far posteriorly as the occiput. It had no definite inducing factors and recently had become practically continuous. He had commenced to suffer from bouts of severe frontal headache. Neurological examination revealed no abnormality. The blood pressure was systolic 200, diastolic 100. The total protein content of the cerebrospinal fluid was 70 mg. per cent. Skiagrams of the skull revealed no abnormality. The radiation of the pain caused difficulty in accepting the diagnosis of trigeminal neuralgia. The raised total protein suggested the presence of an organic lesion, but the absence of any objective signs made diagnosis difficult. Postero-anterior and lateral skiagrams (Figs. 34a and b) of the air-filled fourth ventricle revealed a large fourth ventricle. As seen in the first film the aqueduct of Sylvius and the cisterna magna appeared to be normal (Fig. 34a). The basal and ambient cisterns were next filled (Fig. 34c). These cisterns showed no abnormality. The pons was of normal size. The quadrigeminal plate, outlined between air in the aqueduct of Sylvius and the posterior part of the ambient cistern, appeared to be normal. It was possible, as the result of this investigation, to state that there was no evidence of a space-filling or distorting lesion.

C.D., a man of forty-one years stated that following an abscess in his left ear as a child he had had an intermittent purulent discharge and tinnitus. In January, 1937, he noticed a tendency to stagger at times, without giddiness. He became irritable and complained of an "empty" frontal headache. If he straightened up from a stooping position objects would seem to dance in front of his eyes. After he had smoked a cigarette he would feel quite helpless in the body for about five minutes. He began to notice increasing deafness in the right ear. In February, 1938, a radical mastoid operation was performed on the left side. In hospital the right ear commenced to discharge. The tendency to stagger gradually increased until in October, 1938, he had constant difficulty in walking and was often referred to as being drunk. In January, 1939, his speech became slurred and unsteadiness of his arms developed. Encephalography revealed a very large fourth ventricle in the normal position. The maximum antero-posterior diameter was 2·8 cms. (Fig. 35). The third and lateral ventricles were normal in size, shape and position. The enlarged, undistorted fourth ventricle suggested that atrophy of the cerebellum was the cause of the patient's ataxia. It is probable that the infection of the mastoid air cells played no part in its production. Subsequent to the encephalography a right-sided radical mastoid operation was performed. At the present time the ataxia is more marked, and there is nystagmus, gross slurring of speech and intention tremor. The abdominal reflexes have diminished and the plantar responses are extensor.

B.C., a man of forty-seven years first noticed, three years before admission to hospital, that his left leg became tired if he attempted to walk far. Gradually his lower limbs became weaker, and felt numb from the hips down. A year after the onset he noticed similar progressive weakness and numbness in his arms. Fourteen weeks before being seen, his urine was found to contain sugar in considerable quantities, but after a period of treatment by diet and insulin, the insulin was stopped and he remained sugar-free while he was on a diet of 1500 calories. At this stage, however, he commenced to experience frontal headache and to vomit after food. He began to see double and felt giddy constantly. His voice became hoarse. Examination revealed nystagmus on deviation of the eyes to either side. The right side of the palate was less sensitive than the left, the reflex was absent and pharyngeal stimulation induced a "curtain" movement to the left side. The uvula deviated to the left side on articulation. There was slight weakness of muscular power at the periphery of his limbs, and slight wasting of muscles of the lower limbs, which appeared to be hypotonic. The degree of ataxia present was out of all proportion to the weakness; he was unable to walk without assistance. The deep reflexes were all present, although the ankle jerks were reduced. The abdominal reflexes were absent, the plantar responses were extensor. There was slight loss of superficial sensibility, of peripheral distribution, over all four limbs. Vibration was not

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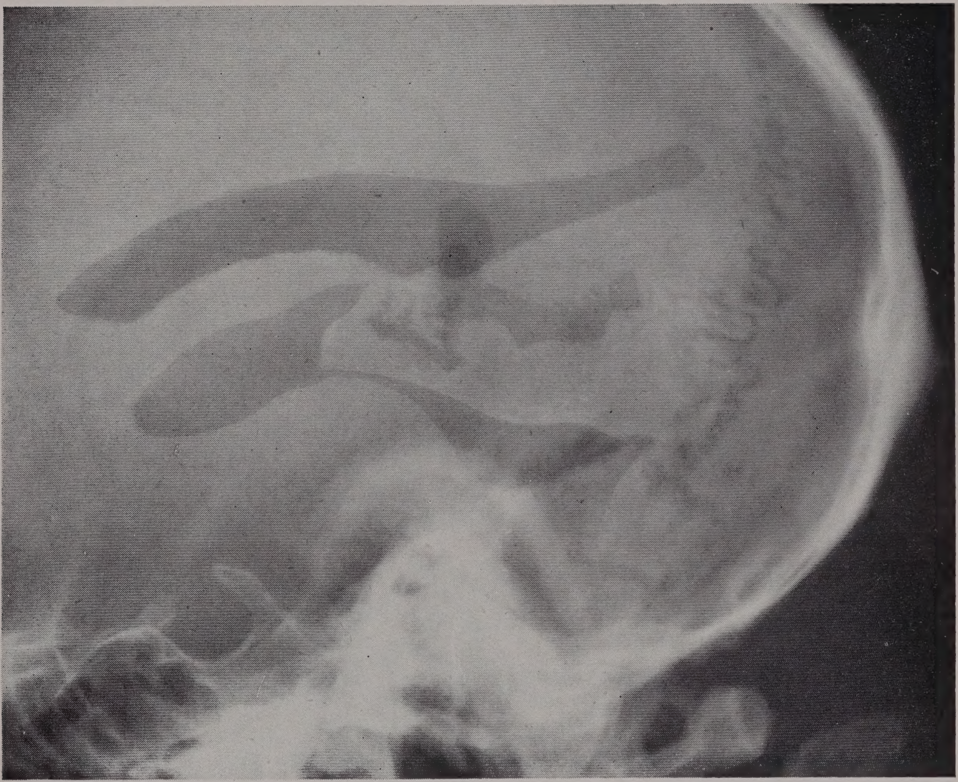

Fig. 35—Dilated fourth ventricle due to cerebellar degeneration. Air is also seen in the cisterna venae magnae cerebri (outlining the quadrigeminal plate).

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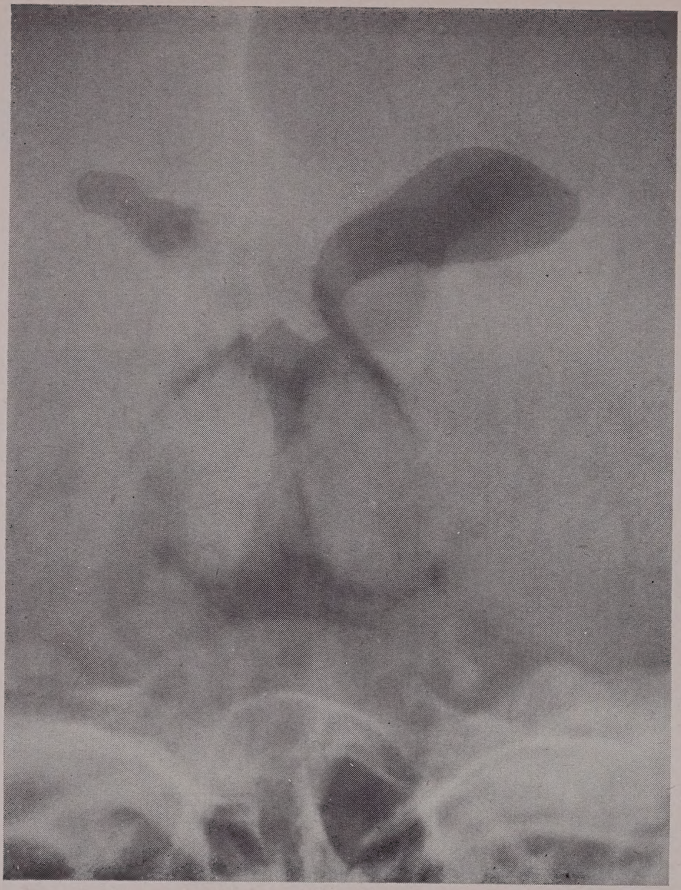
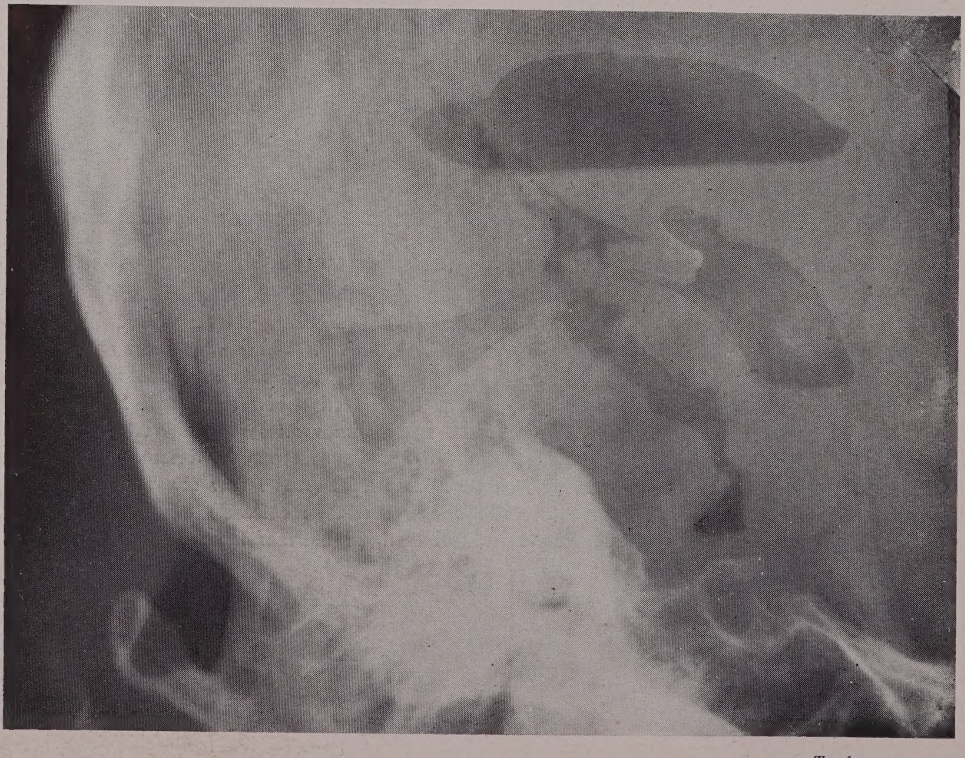


Fig. 36—Normal, but narrow, fourth ventricle.

Fig. 37—Lateral skiagram showing backward displacement of the fourth ventricle and aqueduct of Sylvius due to a tumour within the pons. The interpeduncular and ambient cisterns are outlined. The fourth ventricle is large, the cisterna magna small.



appreciated over the upper and lower limbs, but was felt over the spines of the cervical vertebrae. Slow movements of his great toes were not appreciated. The threshold for distinguishing double contacts was slightly increased in all limbs. General medical examination was normal except for enlargement of the liver. (He had taken large quantities of alcohol in earlier years). His blood pressure was 130 systolic, 90 diastolic. The urine was normal and a glucose tolerance curve was normal. The pressure of the cerebrospinal fluid was 120 mm. There were 54 lymphocytes and 2 large mononuclear cells in three c.mm. of fluid. The total protein was 120 mg. per cent. No reaction occurred in the colloidal gold test. The Wassermann reaction was negative in blood and cerebrospinal fluid. The diagnosis was obscure. Although of slower progress, the case was thought to show some resemblance to those of subacute spino-cerebellar atrophy, described by Greenfield (1934). It was believed that visualization of the fourth ventricle might, therefore, assist in diagnosis and make possible valuable correlation with the subsequent pathological findings. Encephalography revealed no abnormality in the ventricular system, (Fig. 36) and so gave only negative evidence. A year later the patient was commencing to walk without assistance but was still very ataxic. There was more spasticity in the lower limbs.

W.T., a man of seventy-two years commenced to stagger when walking, six months before admission to hospital. At the same time he noticed impairment of hearing in the left ear, with occasional slight tinnitus. Three months later the left side of his face became increasingly numb, and this soon extended to the tongue. Six weeks later his left arm became weak and unsteady and he had some difficulty in initiating micturition. He had no headache or nuchal pain. Examination revealed a moderate degree of impairment of function of the fifth, seventh and eighth nerves on the left side and ataxia of all four limbs, most marked on the left side. He was unable to walk without assistance. The plantar responses were equivocal. The blood pressure was 170 systolic, 120 diastolic. Skiagrams of the skull revealed no abnormality.

The presence of a pontine glioma was considered to be probable, although such unilateral affection of the cranial nuclei is unusual in the diffuse type of gliomatosis which affects the pons. The shadow of the fourth ventricle was larger than usual and, with the aqueduct, it was displaced slightly towards the right side of the posterior fossa. There was definite dorsal displacement from the dorsum sellae (one centimetre more than the high normal) (Fig. 37). In stereoscopic postero-anterior films there appeared to be a convex projection into the upper part of the fourth ventricle. The pontine cistern was narrower than usual. These findings were thought to substantiate the diagnosis of a tumour within the pons, although definite lateral displacement is said by Lysholm (1939) to suggest a lesion within the lateral recess. Twining (1939) points out that a lesion there tends to produce rotation of the ventricle. The diagnosis was thought to be sufficiently definite to render operation unnecessary; but eventually the lateral recess was explored. The auditory nerve appeared to be slightly flattened, but no other abnormality was seen.

Important contributions to the study of displacements of the fourth ventricle produced by pathological lesions have been made by David, Stuhl, Askenasy and Brun (1937), Hyndman (1938), Lysholm (1939) and Twining (1939 a, b).

Chapter VI

THE AQUEDUCT OF SYLVIUS

The shadow of the aqueduct is readily recognized as it passes from the fourth to the third ventricle. In lateral encephalograms air in the interpeduncular cistern, the ambient cisterns and in the aqueduct of Sylvius serve to outline structures related to the incisura tentorii.

Anatomy

The aqueduct of Sylvius is a narrow midline tube which traverses the midbrain, extending from the superior extremity of the fourth ventricle below to the postero-inferior angle of the third ventricle above. It is about 1·5 cm. in length and about 2 mm. in diameter. Its lower part is almost vertical, sloping slightly forwards. In its upper part it curves forwards to enter the third ventricle in an almost horizontal fashion. Anterior to the aqueduct is situated the tegmentum of the midbrain, containing the nuclei of the third and fourth cranial nerves, the red nucleus, and up-going sensory fibres. Antero-laterally are situated the cerebral peduncles. The quadrigeminal plate, bearing the superior and inferior quadrigeminal bodies or colliculi is situated posteriorly. Above this is the pineal gland.

These regions have important relationships with the general subarachnoid space. The cerebral peduncles are separated from the free edge of the tentorium on each side by the ambient cisterns. The quadrigeminal plate is bathed dorsally by the cerebrospinal fluid in the confluence of the ambient cisterns (the cisterna venae magnae cerebri), and so it may be accurately outlined in encephalograms.

Appearances in Skiagrams

Neoplasms very rarely arise within the midbrain or the quadrigeminal plate, but the aqueduct is frequently displaced by tumours growing in neighbouring regions, for example in the posterior part of the third ventricle, the pineal gland, the pons, upper part of the cerebellum, or in the cerebello-pontine angle. An example has already been quoted in the case of W.T. Occasionally, the determination of the anatomical form of the aqueduct and quadrigeminal plate is of value in demonstrating an intrinsic lesion.

T.L., a male of twenty years was admitted to hospital because of headache and failing vision. He stated that he had always had a large head. When he was six years of age he was "ill with paralysis for a long time." No further details of the illness could be obtained. Two years before admission he commenced to suffer from frontal headaches which he related to occupational eyestrain. Occasionally when the headache was severe he vomited. In the six months before admission he suffered from three generalized convulsions, and over this period his vision was failing. The head circumference was twenty-four inches. The visual acuity in the right eye was 6/6, in the left 6/18 (Snellen). There was a bilateral symmetrical altitudinal defect in the visual fields, most marked in the left-sided upper fields. Both optic discs were pale,

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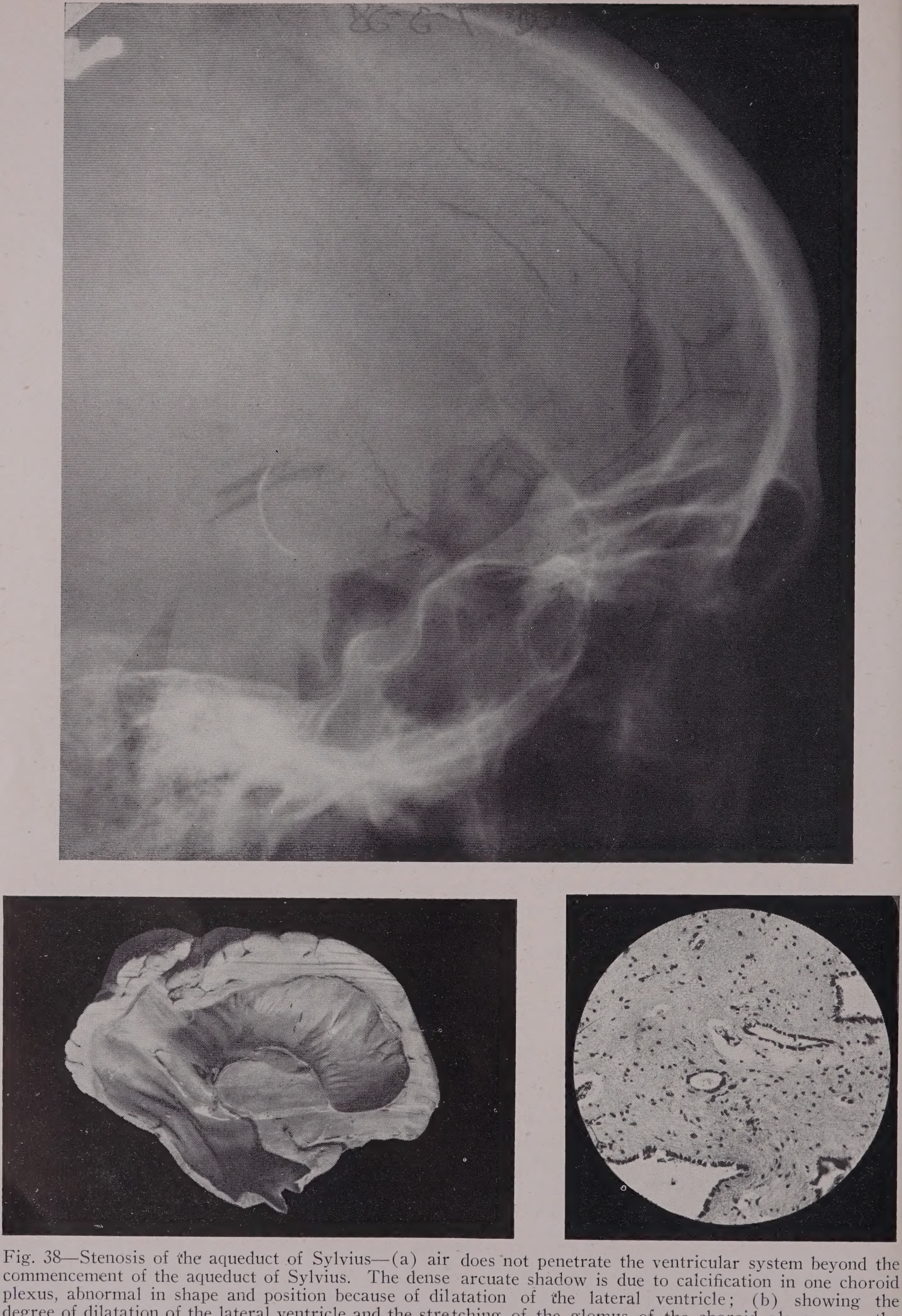

Fig. 38—Stenosis of the aqueduct of Sylvius—(a) air does not penetrate the ventricular system beyond the commencement of the aqueduct of Sylvius. The dense arcuate shadow is due to calcification in one choroid plexus, abnormal in shape and position because of dilatation of the lateral ventricle; (b) showing the degree of dilatation of the lateral ventricle and the stretching of the glomus of the choroid plexus over the anterior wall of the trigone; (c) section of the mid-brain showing fragmentation of the aqueduct of Sylvius.

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their appearance suggesting optic atrophy consecutive to papilloedema. The deep reflexes were extremely active and the left plantar response was less definitely flexor than the right.

Skiagrams of the skull revealed a generally enlarged skull of normal thickness. The sella turcica was small. Three cm. above and behind the posterior clinoid processes there was a thin, arcuate line due to calcification, its concavity directed forwards (Fig. 38a). In stereoscopic views it was seen to lie to the right of the midline, but no calcification could be identified in antero-posterior or postero-anterior views. The cerebrospinal fluid was under an initial pressure of 150 mm. and contained 50 mg. of protein per cent. Encephalography revealed a fourth ventricle which was small in its antero-posterior measurement but normal in position. It narrowed above to the aqueduct of Sylvius, but the shadow extended only about 5 mm. above the level of the posterior clinoid processes (Fig. 38a). Introduction of more air failed to secure further penetration of the ventricular system. The air rose to outline the interpeduncular and chiasmatic cisterns. The callosal and cingulate sulci were well outlined and were nearer the vertex than usual. The relation between these findings and the intracranial calcification, which was thought to represent the primary lesion, was not realized. As the circular nature of the shadow suggested an aneurysm arteriography was performed by Mr. A. E. Coates. The intracranial part of the internal carotid artery appeared to be straightened and its terminal part was vertical. The pericallosal artery was elevated. The branches of the middle cerebral artery were spread apart, one branch being elevated and the lower branch displaced downwards. No aneurysm was seen.

Eventually, owing to the severity of the headache and increasing visual failure, exploration was undertaken. The chiasmal region appeared normal. No calcification could be detected with a brain needle. Finally the greatly dilated lateral ventricle was opened but no tumour was found. The patient died after operation. The lateral ventricles were enormously dilated, the temporal horns being most affected (Fig. 38b). The third ventricle was widened and the infundibulum greatly distended. The fourth ventricle was small. It was impossible to pass a probe along the aqueduct. Microscopic examination of serial sections cut transversely across the midbrain revealed a series of ependyma-lined cavities of varying calibre (Fig. 38c). In one field seven such spaces could be seen. The calcification was found to be in the choroid plexus on the right side. It differed from the usual shadows cast by the choroid plexuses in size, shape, position and in being unilateral. The dilatation of the ventricles, due to a congenial stenosis of the aqueduct of Sylvius, explained the unusual shape and position of the shadow. The glomus of the choroid plexus was stretched over the anterior wall of the trigone which, as it swept around from the body of the ventricle to the temporal horn, was placed more anteriorly than usual. The attenuation of the sheet of choroid plexus was responsible for the absence of a discernible shadow in antero-posterior and postero-anterior skiagrams.

Lysholm (1938, 1939) has made important contributions to the study of displacements of the aqueduct as seen in ventriculograms. He shows that in all cases the direction of displacement of the aqueduct is away from the position of a tumour. Neoplasms in the upper parts of the vermis and cerebellar hemispheres produce, in addition, a characteristic dorsal kink in the supratentorial part of the aqueduct. The longer intratentorial part shows, in addition, a forward bow-like displacement; and when the lesion is in one cerebellar hemisphere, contralateral displacement occurs as well.

Chapter VII

THE THIRD VENTRICLE

The ease with which this cavity may be filled, and its relation to the subarachnoid cisterns, permit the accurate delineation of its important boundaries. Its median position makes it a useful index of the lateral displacement of supratentorial structures.

Radiological anatomy

The third ventricle appears, in pneumograms, as a roughly quadrilateral shadow (Figs. 6b and 53a). The upper margin is usually smooth and convex and anatomically it is limited by the tela choroidea of the third ventricle, composed of the ependyma of the roof plate of the third ventricle and the pia mater of the velum interpositum bearing the parasagittal strips of choroid plexus. Above the velum interpositum is the fornix and above the fornix is the corpus callosum. At each side of the antero-superior angle of the ventricle, the interventricular foramen of Monro communicates with the lateral ventricle of its own side. The foramen lies between the anterior column of the fornix antero-medially and the thalamus postero-laterally. It is roofed by ependyma, protruding into which is the anterior extremity of the velum interpositum, bearing the choroid plexus. In encephalograms the foramina can frequently be seen passing from the antero-superior extremity of the shadow of the ventricle to the lateral ventricles (Figs. 29 and 53a). The anterior wall of the ventricle slopes downwards and forwards (Figs. 29 and 63) and is formed from above downwards by the anterior pillar of the fornix, the anterior commissure and the lamina terminalis (Fig. 7a). The latter is related anteriorly to cistern of the lamina terminalis (Figs. 7a and 63). Below, the lamina terminalis is attached to the upper surface of the optic chiasma in such a manner as to form the optic recess.

The floor of the ventricle is formed, from before backwards, by the optic chiasm, the tuber cinereum bearing the infundibulum which contains the infundibular recess, the corpora mamillaria and the mid-brain. In encephalograms the anterior part of the floor is best seen in lateral views taken with the brow up (Fig. 63). The optic recess and the infundibular recess may be well seen. This part of the floor is related externally to interpeduncular and chiasmatic cisterns (Fig. 63). The posterior part of the floor is smooth and slightly convex and lies in a more or less horizontal plane. At its posterior end the aqueduct of Sylvius leaves the ventricle (Figs. 6b and 37). The posterior wall of the ventricle is its shortest wall. It is formed by the pineal gland above and the posterior commissure below. In encephalograms a large recess (the suprapineal recess) is seen projecting posteriorly from the postero-superior angle of the ventricular shadow (Fig. 6b). If the pineal gland be calcified this recess is seen to be situated above the flecks of calcification. A small pineal recess may sometimes be seen as it projects into the pineal gland. Below this recess the shadow is slightly convex and is related to the posterior

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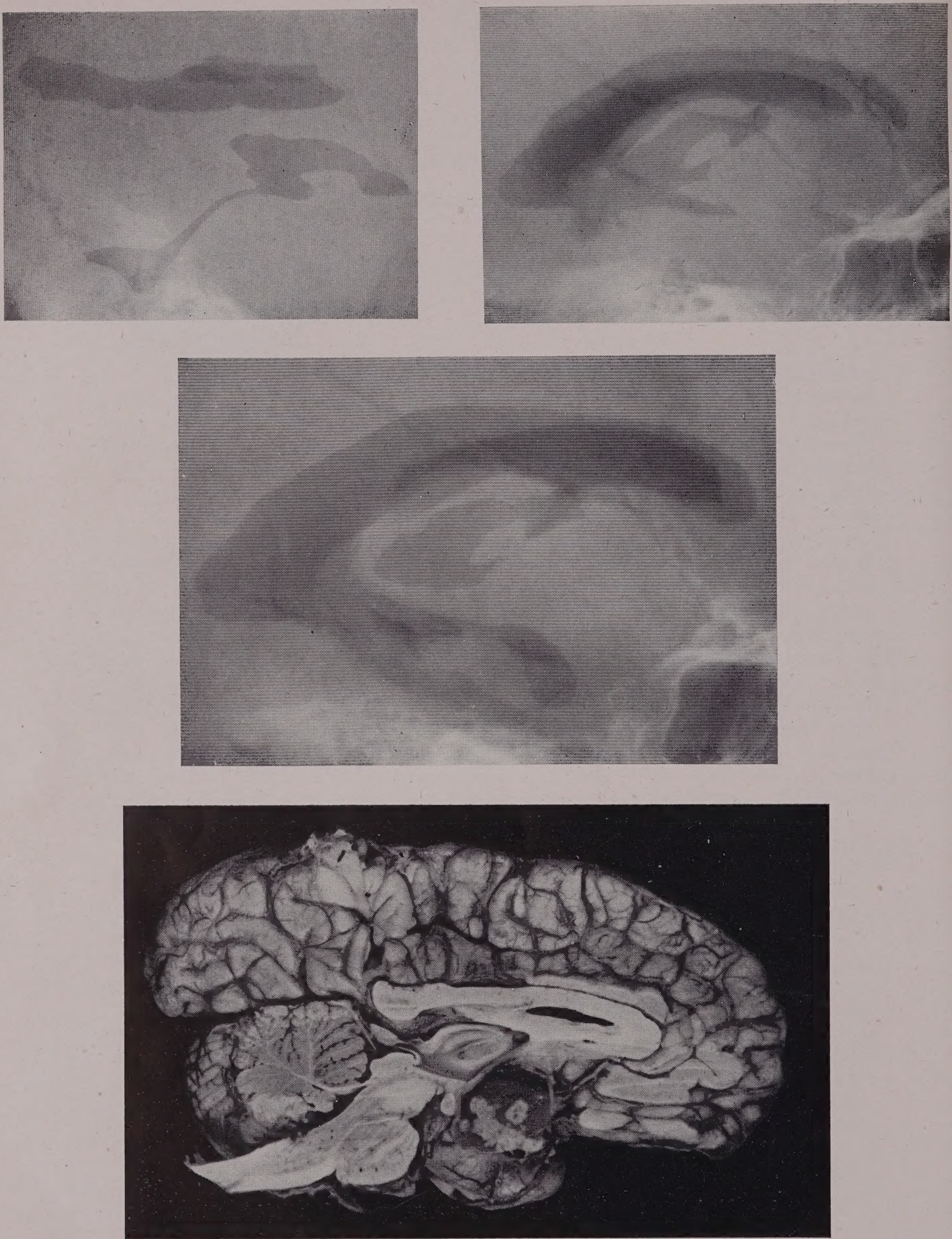

Fig. 39—The third ventricle of a patient with a supra-sellar craniopharyngioma—(a) lateral view, with head flexed, during filling; (b) lateral view, with head erect—20 c.cm. of air; (c) lateral view, right side uppermost; (d) mid-line section of brain and tumour.

To face page 57.

commissure. The aqueduct of Sylvius curves away below the commissure. This boundary of the ventricle is related externally to the cisterna venae magnae cerebri. The lateral walls of the ventricle are formed by the thalami above, and the hypothalami below. The boundary between these structures may be delineated by a line drawn between the interventricular foramen and the aqueduct of Sylvius. The thalami are frequently joined across the ventricle by the middle commissure, which is readily recognized, in lateral views, as a circular or oval shadow of varying size. In sagittal views with the brow up the anterior part of the ventricle is seen to be narrow from side to side, (Fig. 8c and 43d). On each side of its upper part the interventricular foramina may be seen extending into the lateral ventricles. The posterior part is more oval in outline, being wider and of smaller vertical dimension, and is often clearly seen in postero-anterior skiagrams, taken with the occiput upwards.

Illustrative cases

Encephalography may prove useful in elucidating some of the causes of visual failure, especially in the recognition of space-filling lesions in the suprasellar region. Such cases constitute a relatively frequent diagnostic problem. For this reason a typical case will be described and this will be followed by a short discussion of the usefulness of the method in excluding the presence of a neoplasm.

T.A., a woman of forty-two, complained of visual failure twelve months before admission to hospital. She had noticed that the temporal field of the left eye was becoming constricted. Regular examinations by an ophthalmologist revealed a large scotoma on each side between the macula and the blind spot. For eight months she had complained of frontal headaches, extending to the occiput and the back of the neck. She had gained two stone in weight and the menses had ceased. On examination the left eye was blind. The visual acuity of the right eye was 6/36 (Snellen) and only a small field remained in the upper nasal quadrant. There was bilateral optic atrophy. The pressure of the cerebrospinal fluid was 150 mm. It contained two lymphocytes and one large mononuclear cell per c.mm. and 150 mg. of protein per cent. The Wassermann reaction was negative. The pituitary fossa was small; the posterior clinoid processes and the dorsum sella appeared to be somewhat decalcified.

In the postero-anterior views taken during filling the third ventricle appeared to be abnormally broad (1 cm.). In lateral view with semi-flexed head the posterior part of the third ventricle filled well, but fluid was not displaced below the level of entry of the aqueduct of Sylvius (Fig. 39a). A large middle commissure interrupted the shadow of the air in the ventricle. At a later stage of filling, the lateral skiagram taken with the head erect showed that what appeared to be a fluid level in the previous film was really due to a filling defect, apparently produced by a tumour projecting into the antero-inferior part of the ventricle (Fig. 39b). This filling defect was also shown in lateral views taken with the patient in the supine position (Fig. 39c).

The patient died after exploration. At autopsy a tumour presented in the suprasellar region between the mamillary bodies and optic chiasma, which was incorporated in the tumour (Fig. 39d). The tumour pressed upwards into the antero-inferior part of the third ventricle. It was encapsulated and consisted of a lobulated, white, solid cone projecting into a mass of mucoid material. Microscopic examination showed it to be a craniopharyngioma.

When the vertex is uppermost the antero-inferior part of the third ventricle does not fill with air, although occasionally a surprising amount of this part of the ventricle is seen (Fig. 29). If further information of the optic recess and the infundibulum is required a lateral view is taken with the forehead uppermost (Fig. 63). The column of air in this part of the third ventricle is thin and does not throw a dense shadow.

If a suprasellar lesion is suspected an attempt is usually made to fill the cisterns in this region, as well as the third ventricle. An abnormality of the outlines of the third ventricle, chiasmatic cistern or optic nerves may point to the presence of a space-filling lesion, which may be one of a number of types. It is probable that such a lesion is absent if the third ventricle and the cisterns appear normal. However, three cases have been examined in which the pattern of the visual fields suggested chiasmal involvement. In two the optic discs were pale. One of these, and the third case, suffered from headaches. In none was a definite abnormality seen in the encephalograms. It is possible, but unlikely, that a small neoplasm might partially obliterate the basal cisterns and yet allow air to enter in sufficient quantity to cast a shadow which could not be differentiated from the normal. Further experience, including prolonged observation of such cases, is necessary before a definite statement can be made in the matter.

Hamby and Gardner (1935) have studied the encephalograms of a number of patients with suprasellar tumours. They point out that the abnormalities seen are, firstly, obliteration of the cisterna chiasmatis; secondly, distortion of the ventricular shadows depending upon the size and location of the tumour; and thirdly, diminution of the frontal cerebral subarachnoid markings, due to blockage of the cisterna chiasmatis. Amongst others, Lysholm (1938) and Twining (1939) have added much to our knowledge of the effort of neoplasms upon the third ventricle.

In a series of cases some unusual pictures may arise, and the study of these may lead to a diagnostic advance.

C.M.E., a woman of forty years suddenly experienced right-sided frontal headache and a shooting pain in the right eye, and commenced to vomit. Heavily blood-stained cerebrospinal fluid was evacuated at the first lumbar puncture and two days later yellow fluid was removed. She improved rapidly at first, but one day during convalescence she felt faint, and after this she was unsteady on her feet. Occasionally she saw double, but more frequently objects and people appeared horrible and grotesque. Her eyesight progressively failed and five months after the onset the visual acuity was 6/36 in each eye. There was bilateral ptosis and the pupils were large and unequal, reacting poorly to light and accommodation. She was unable to look upwards and although lateral movements were full, adduction of the right eye fatigued rapidly. There was slight intention tremor in both upper limbs. Her gait was ataxic, but this was partly due to diplopia and to psychological causes. Skiagrams of the skull were normal. The cerebrospinal fluid was normal.

The first film taken during the introduction of air revealed a diverticulum passing upwards and outwards to the right from the third ventricle. Figure 40a shows this appearance at a later stage of filling. A fuller analysis of later films showed that the diverticulum arose from the lower and posterior portion of the third ventricle. It extended thence 2·2 cm. towards the body of the lateral ventricle. Filling of the aqueduct and the posterior part of the ambient cistern (the cisterna venae magnae cerebri) showed clearly that the pineal gland and the quadrigeminal plate were of normal size (Fig. 40b). Encephalography was repeated a year later. The lateral ventricles were each 1 mm. wider than before. The appearance of the diverticulum, the third ventricle, the aqueduct and the quadrigeminal plate was unaltered. There has been no alteration of signs or symptoms since the performance of this investigation.

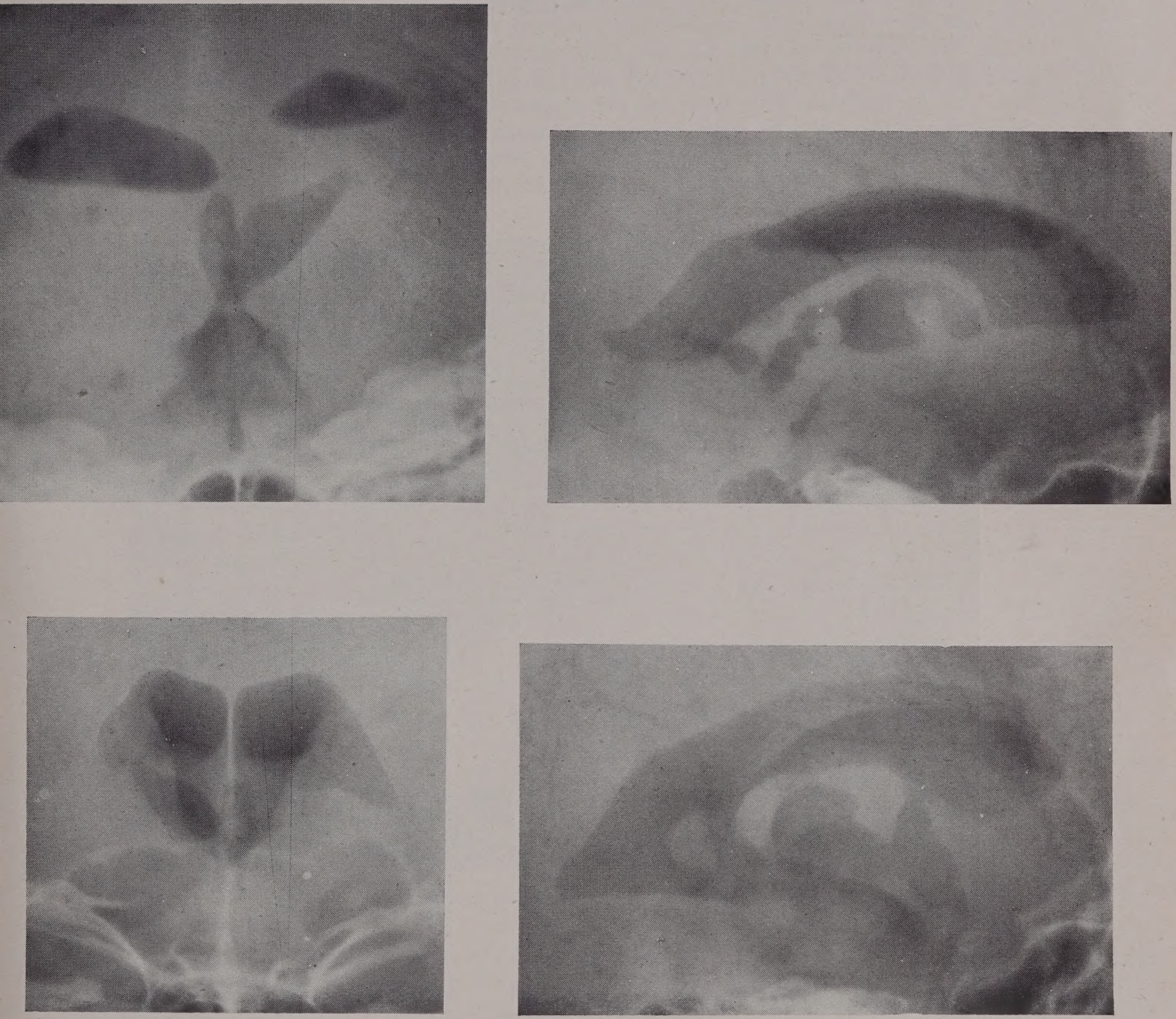

Fig. 40—A diverticulum of the third ventricle—(a) postero-anterior film during filling; (b) lateral film after air had been introduced into the subarachnoid cisterns to outline the quadrigeminal plate and the pineal gland; (c) antero-posterior film with head erect; (d) lateral view, right side uppermost.

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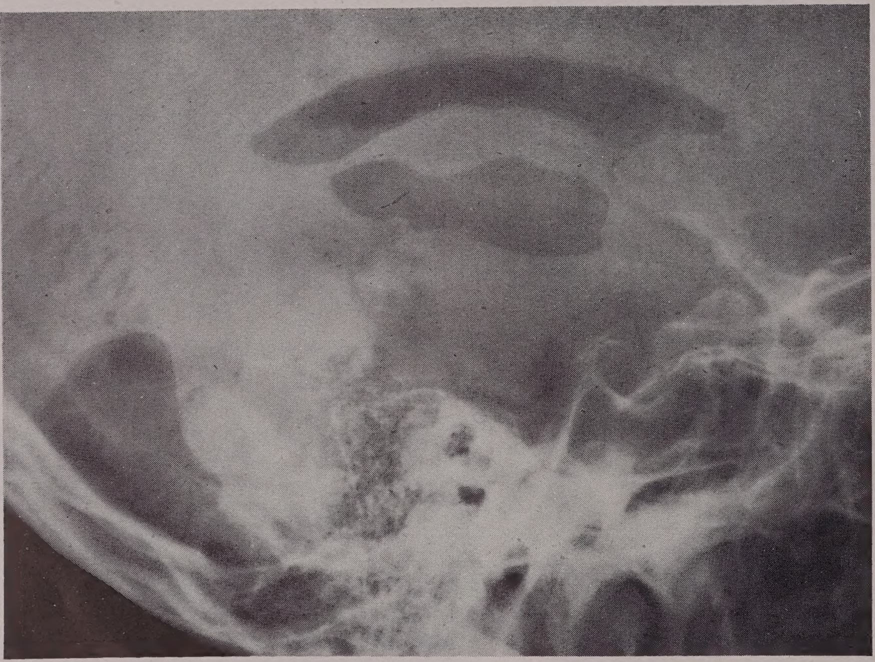

Fig. 41—A large suprapineal recess. The cisterna magna also is unusually extensive.

It is probable that the cavity was due to an intracerebral haemorrhage rupturing into the third ventricle, possibly from a capillary haemangioma or an intra-cerebral aneurysm. The lesion must have been of sufficient extent to affect the upper part of the mid-brain. It is unlikely that the haemorrhage occurred within a glioma for the cavity would hardly have persisted, and the passage of a year produced no change. The rupture of an intracranial aneurysm in some situations (e.g., on the anterior cerebral and on the middle cerebral artery in the Sylvian fissure) may result in tearing up of the neighbouring cerebral substance, but the shape and position of the cavity made it unlikely that a causal aneurysm was situated upon the extracerebral vessels. An aneurysm may, however, develop in the brain itself, a case having recently been reported by Hermann and Macgregor (1940).

Anatomical variations

In cases where there was no obvious abnormality the maximum width of the shadow of the third ventricle, seen in antero-posterior skiagrams, varied between 3 and 9 mm., 4 to 6 mm. being the commonest measurement. The suprapineal recess is usually small but in three patients in this series the recess was very much larger than usual (Fig. 41). In these cases it was probably a congenital anomaly, for there was no evidence of any other pathological lesion, and in one case (that illustrated in figure 41) the separation between the lateral ventricle was much greater than usual, apparently due to the presence of a large cavum septi pellucidi. When the pressure within the third ventricle is raised the suprapineal recess may become distended, for the wall here is weak, as it is in the region of the infundibulum.

Chapter VIII

THE LATERAL VENTRICLES

The lateral ventricles are developed as diverticula (contained within the expanding cerebral hemispheres) of the third ventricle, communicating with it through the interventricular foramina. As the temporal lobe develops by a process of expansion and rotation from the posterior and inferior part of the cerebral vesicle, it carries with it a diverticulum of the original simple cavity, forming the temporal horn. The occipital horn develops similarly in the occipital lobe. The cavity of the original vesicle remains as the anterior horn and body of the ventricle. Thus three limbs come to radiate from a posteriorly-situated common cavity, the trigone. This is actually composed of those parts of the body, occipital and temporal horns, which meet opposite the splenium of the corpus callosum. In discussing pneumograms it is convenient to regard the trigone as an entity. In this a departure will therefore be made from the usual anatomical description.

Anterior horn and body

The superior limb of the ventricle, passing forwards from the trigone comprises the body and the anterior horn. The anterior horn is defined as that part lying in front of the interventricular foramen. It passes forwards for a little more than a centimetre and then deviates laterally, anterior to the head of the caudate nucleus, to end blindly in the substance of the frontal lobe. Immediately in front of the foramen, the ventricle is triangular in section (Fig. 42), the corpus callosum forming the roof. The medial walls of the two ventricles lie close together, being separated only by the septum pellucidum above and the anterior pillars of the fornix below, but anteriorly where they diverge laterally, they are separated by the fibres of the corpus callosum constituting the forceps minor. These fibres also form the roof and the anterior limits of the ventricles. The infero-lateral boundary of the anterior horn is formed by the caudate nucleus.

The body of the ventricle passes back from the interventricular foramen in a gentle arch, the thalamus (covered by the fornix and the choroid plexus) bulging into the lower part and thus rapidly diminishing the vertical diameter (Fig. 42). The cross-section of the ventricle thus changes from triangular (with its long axis obliquely vertical) to quadrangular (with its long axis more or less horizontal). The body is roofed by the corpus callosum and the medial wall is formed by the septum pellucidum anteriorly and the body of the fornix posteriorly. The lower or infero-lateral wall is formed by the tail of the caudate nucleus laterally and by the thalamus (covered by the body and taenia of the fornix) medially. Between the caudate nucleus and the thalamus the upper part of the stria terminalis is here situated. Between the stria and the body of the fornix, the choroid plexus projects into the ventricle, its vascular tissue being covered by ependyma and by the pia mater of the velum interpositum. An important relation is the

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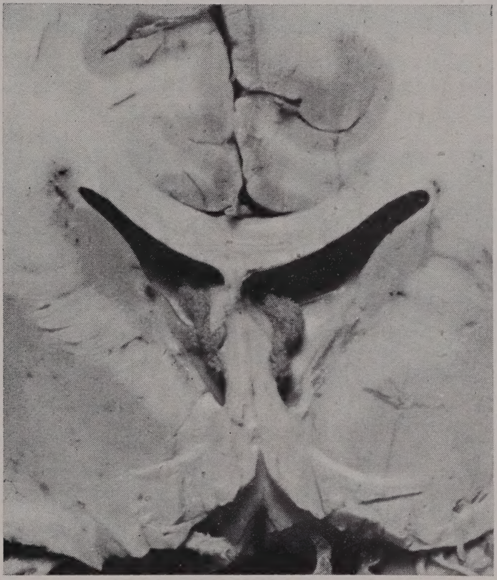

Fig. 42—Coronal section immediately in front of the interventricular foramina. The abrupt change of section between the posterior part of the anterior horn and the body is seen. The choroid plexus lies upon the anterior extremity of the thalamus.

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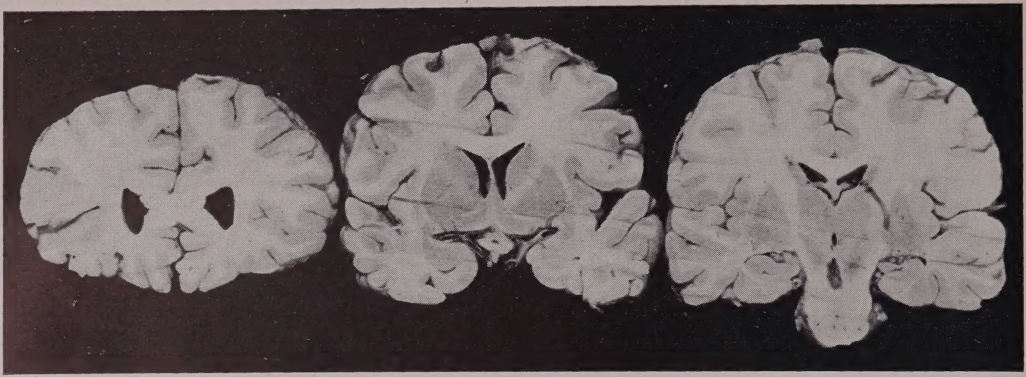

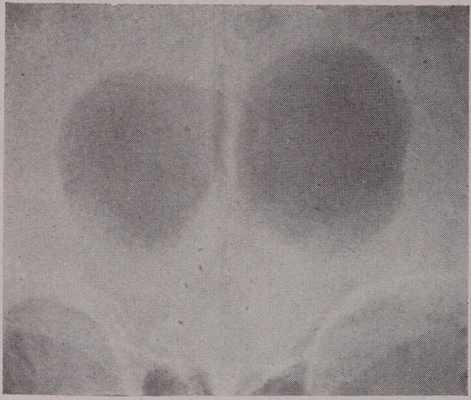

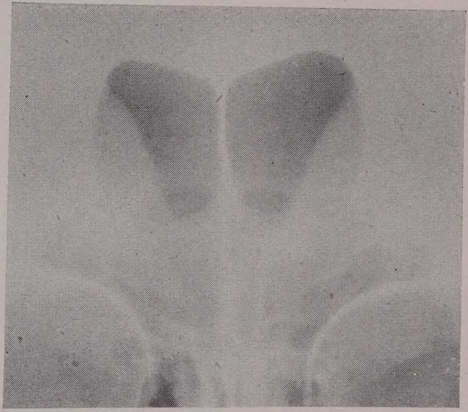

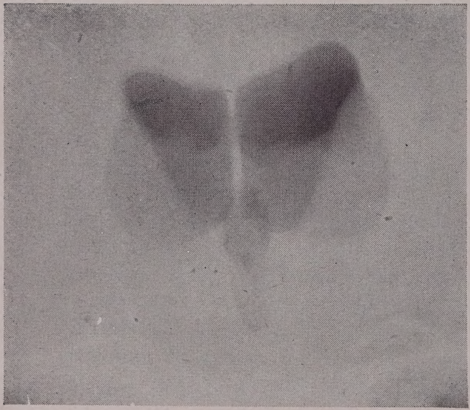

Fig. 43—The component parts of the shadow seen in antero-posterior skiagrams taken with the forehead uppermost—(a) coronal sections through the tip of the anterior horns, the posterior part of the anterior horns, and the middle of the body of the lateral ventricles; (b) skiagram showing the anterior poles; (c) after more air has been introduced, the shadows of the anterior horns anterior to the interventricular foramina are added; (d) the addition of more air adds the shadows of the bodies and of the third ventricle.

internal capsule which is lateral to the thalamus and to the head of the caudate nucleus. The posterior part of the body is smaller than the anterior. It is similar in shape, but the diverging posterior columns of the fornix replace the septum pellucidum as the medial boundary. The posterior parts diverge laterally as they swing downwards around the pulvinaria of the thalami to merge into the trigonal portions. The appearances in normal encephalograms are demonstrated in figures 8 and 43. The bulbous anterior extremities of the ventricles cast smooth semi-circular shadows on each side of the darker triangular shadows of the posterior parts of the anterior horns. If the quantity of air is adequate, dark quadrangular shadows may be seen superimposed upon the upper parts of these triangles. These represent the cross-sections of the middle parts of the bodies of the ventricles. The less dense triangular area below the quadrangle indicates the anterior part of the thalamus.

The space between the shadows of the ventricles usually measures about 3 mm., but occasionally it is much wider. This may be due to the presence of a neoplasm; for example, the shadow of a colloid cyst of the third ventricle has been seen causing an apparent expansion of the lower end of the septum pellucidum. If, however, the outlines of the third and lateral ventricles are not distorted, any widening of the septum is likely to be due to the presence of a cavum septi pellucidi—a fluid-filled cavity between the two layers of the septum. Such a cavity may communicate with the lateral ventricles by deficiencies in its tenuous walls. It may then fill with air, and throw an elongated shadow between the ventricles. Such a widening of the septum pellucidum was observed in three cases, and in one of these the cavum contained air. In this instance the ventricles were dilated. In the absence of a cavum, fenestration of the septum is more likely to occur when there is internal hydrocephalus.

The trigone

The trigone is, as described above, the region of confluence of the body, temporal and occipital horns. Its upper part is formed by most of the posterior third of the body of the ventricle. It is usually situated opposite the splenium of the corpus callosum, although the exact relationship is very variable. The anterior margin may be opposite the tip of the splenium, or as much as 1 cm. in front of it. The size of the trigone is very variable, and in normal cases when it is large it may extend as much as 3 cm. behind the tip of the splenium. As seen in lateral skiagrams it is triangular; but in postero-anterior skiagrams it is seen sloping downwards and laterally as an irregular, elongated, quadrangular shadow, at an angle of about 45 degrees to the horizontal plane (Fig. 10c). As viewed from behind in section, the anterior boundary of the trigone is seen to possess two long margins, which may be differentiated as supero-lateral and infero-medial. The lower margin connecting these lies in a horizontal plane, and is longer than the upper. In the upper and lower parts of this anterior boundary are spaces through which trigone is continuous with the main body of the ventricle above and the temporal horn below. Between these two spaces the rounded middle two-thirds of the anterior wall is limited, laterally and above, by the fibres of the corpus callosum and, medially by fibres passing to the internal capsule. The choroid plexus swings from the body of the ventricle to the temporal horn across the anterior wall, here formed by the pulvinar of the thalamus.

Below the plexus, and above the posterior extremity of the hippocampus, the anterior wall contains the fimbria of the hippocampus, which swings medially and upwards to become the posterior column of the fornix. The trigone may be visualized as an irregular pyramid, with its apex directed backwards, its base being the anterior boundary already described. The sides of the pyramid are formed chiefly by fibres of the corpus callosum, the tapetum constituting the supero-lateral wall, the forceps major the infero-medial wall. Posteriorly the fibres of the forceps are heaped up to indent the ventricle, forming the bulb of the posterior horn. At a lower level, the fibres travelling medial to the deep indentation of the calcarine fissure form the calcar avis. A little further forwards the hippocampus enters into the formation of the lower part of the infero-medial wall. The floor, between the supero-lateral and infero-medial walls is formed by the collateral triangle, deep to the collateral fissure. Above, the two side walls meet in a narrow roof. Posteriorly, the trigone leads directly into the occipital horn.

Occipital horns

From the trigone the occipital horn extends backwards and medially into the occipital lobe. Medial to the anterior portion of the horn are the fibres of the forceps major, heaped up into the bulb of the posterior horn and the calcar avis. Above and lateral to it are the fibres of the tapetum.

TABLE II

Irregularity of occipital horns

Condition	Cases
Present and symmetrical	18
Both absent	20
Both present, but unequal	32
One absent	20

The occipital horns may be demonstrated in a number of different views. Those which have been found most useful have already been described, but may be summarized here:

Postero-anterior films taken with the occiput up. The occipital horn, extending at right angles to the film, produces a dense circular area in the shadow of the trigonum.

A lateral film may be taken with the occiput upwards. The air is now in the highest parts of both ventricles, the occipital horns and the trigones.

The baso-vertical view displays the length of each occipital horn.

Lateral films with one side of the head uppermost show the occipital horn of that side.

In *lateral* skiagrams taken during filling with the head flexed, the occipital horns are the highest parts of the lateral ventricles and are well seen.

The size of the occipital horns varies greatly. Sometimes one or both may be absent (Fig. 44a), or the horns may be asymmetrical (Fig. 44b) without pathological cause. When the horn is absent, the rounded elevation of the calcar avis usually forms the posterior extremity of the trigone as seen in lateral views. Although well known, the point is emphasized, for it is sometimes made the basis of erroneous diagnoses. A comparison was made of the occipital horns in a series of 90 cases in which they were clearly visible. The results were as shown in table II.

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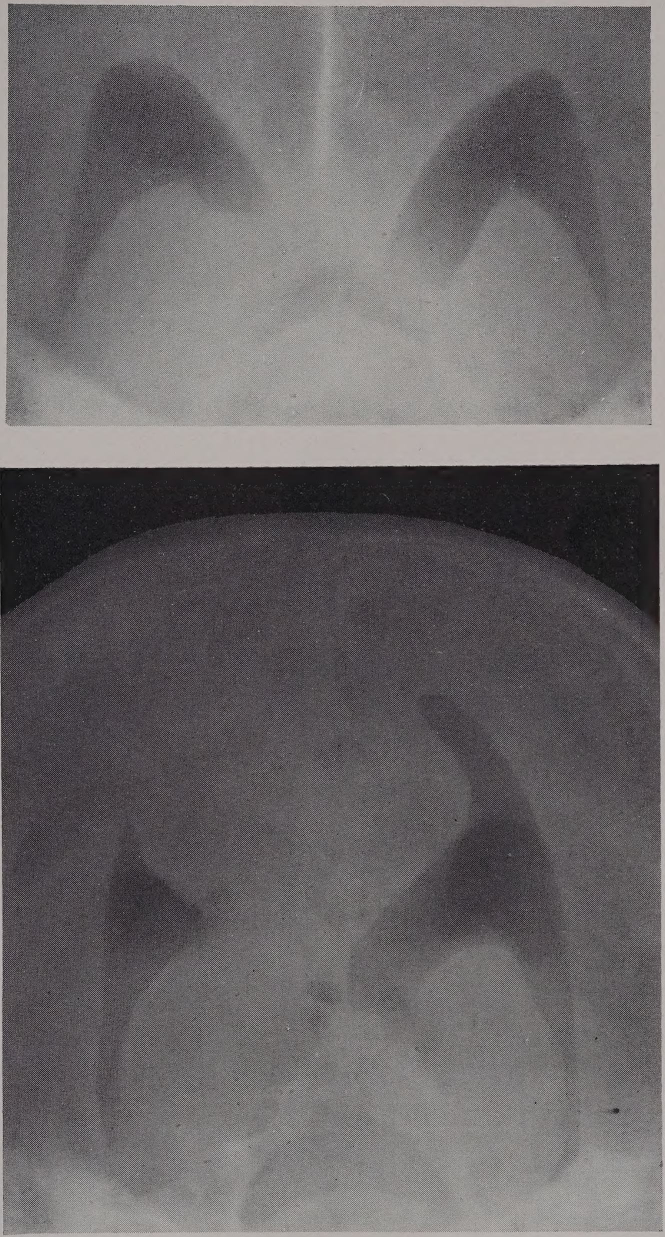

Fig. 44a, b—Variations in the development of occipital horns.

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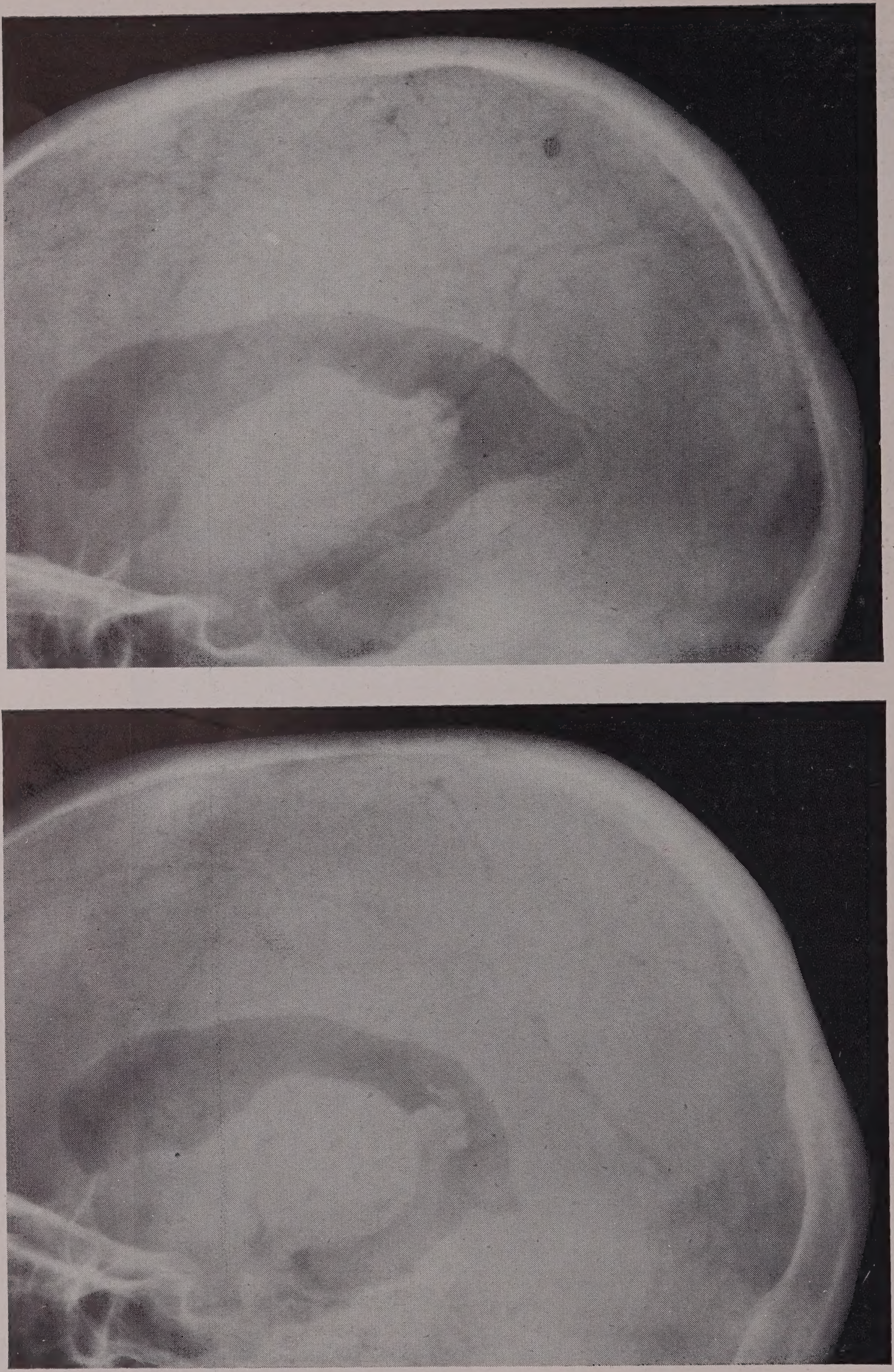

Fig. 45—Obliteration of the right occipital horn and forward displacement of the trigone produced by a meningioma of the falx above the right calcarine fissure. (For ease of comparison the second film is reversed.)

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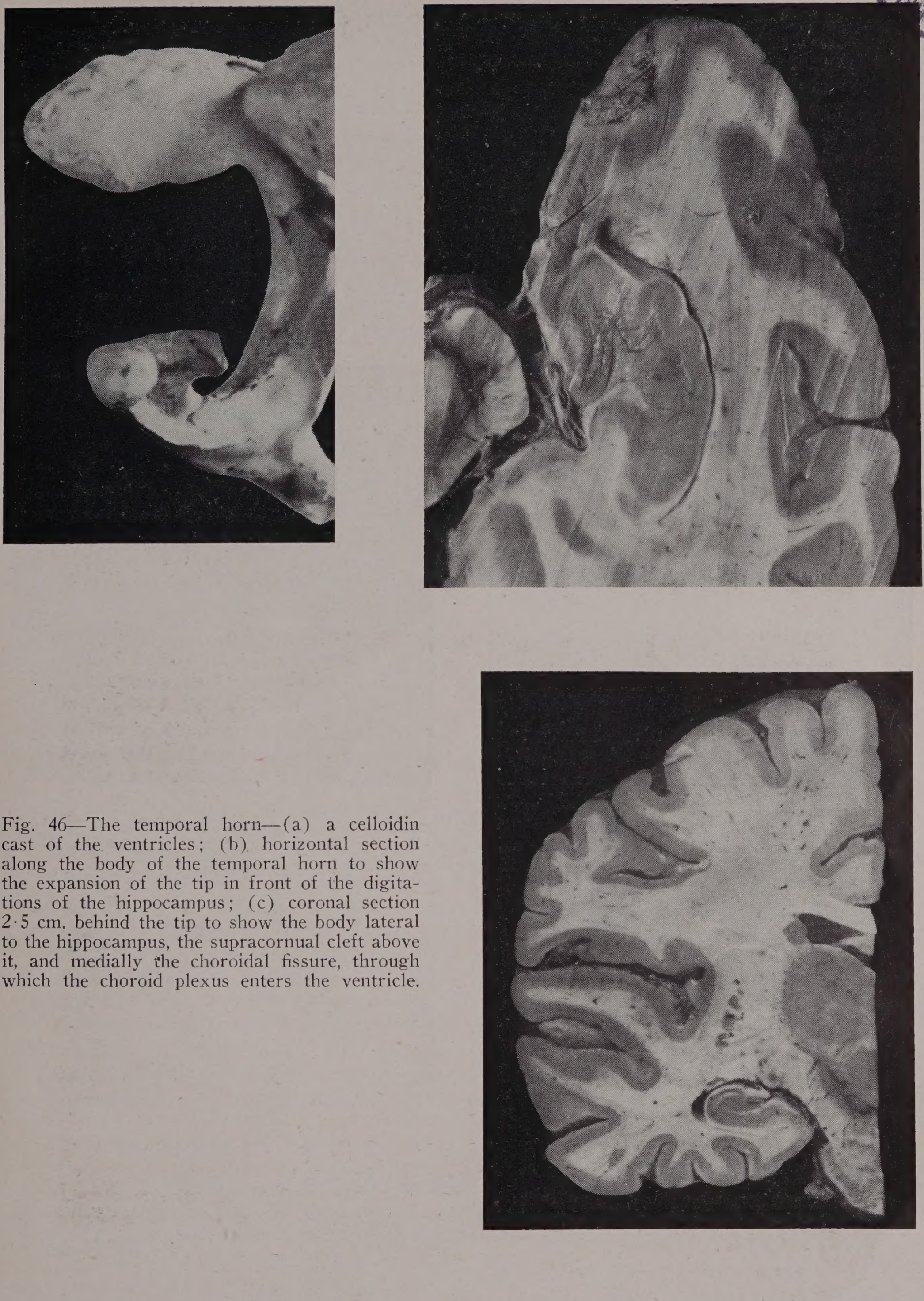

Fig. 46—The temporal horn—(a) a celloidin cast of the ventricles; (b) horizontal section along the body of the temporal horn to show the expansion of the tip in front of the digitations of the hippocampus; (c) coronal section 2·5 cm. behind the tip to show the body lateral to the hippocampus, the supracornual cleft above it, and medially the choroidal fissure, through which the choroid plexus enters the ventricle.

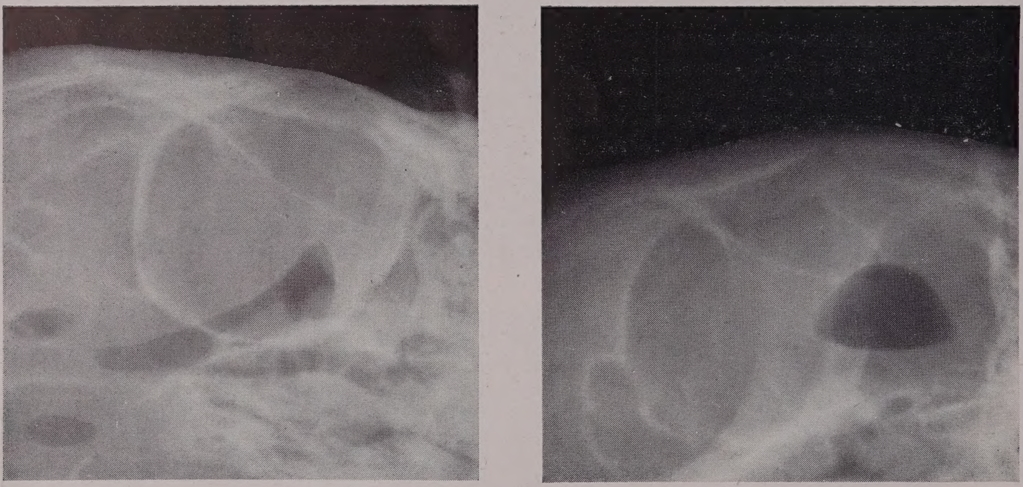

Fig. 47—The alteration produced in the temporal horn by a vascular lesion. Antero-posterior and postero-anterior views with opposite sides of the head uppermost. (For ease of comparison the second film is reversed.)

In contrast, figure 45 shows asymmetry of the occipital horns and trigones produced by a meningioma growing from the falx just above the calcarine fissure.

Temporal horns

From the trigonum the temporal horn curves gently downwards and forwards and then more directly forwards, to end 2 or 3 cm. behind the tip of the temporal lobe (Fig. 46). The prominence of the hippocampus projects into the infero-medial wall of the ventricle along its entire length, except towards the tip (Fig. 46b, c). In front of the termination of the hippocampal elevation, the tip of the ventricle turns medially and, to a varying degree, downwards (Fig. 46a, b). Seen in cross-section the temporal horn is crescentic along most of its length, the concavity being directed downwards and medially (Fig. 46c). The outer (or supero-lateral) wall is formed by the fibres of the tapetum of the corpus callosum, with the tail of the caudate nucleus at its medial extremity. The inner (or infero-medial) wall is formed by the convex hippocampus. Above the hippocampus is the fimbria of the hippocampus, and between this and the tail of the caudate nucleus is the choroid fissure through which the choroid plexus gains access to the ventricle. Below the hippocampus the white matter is elevated over the deep lateral projection of the collateral fissure, forming the collateral eminence. Childe and Penfield (1937) have applied these anatomical facts to the explanation of the appearances of the temporal horns in lateral pneumograms. The part lateral to the hippocampus—which they term the body—occupies a vertical plane, and the part above it—the supracornual cleft—a roughly horizontal plane. A ventricular cast (Fig. 46a) shows the supracornual cleft above the groove made by the hippocampus. The two portions may be recognized in encephalograms. The supracornual cleft, having its widest diameter along the direction of the centre-ray in lateral skiagrams, casts a comparatively dense shadow. The body of the ventricle may be undefined, or may be faintly outlined, as the layer of gas through which the rays pass is frequently only one or two millimetres in thickness. Childe and Penfield also point out that "when the ventricle is moderately dilated the temporal horn becomes rounded as well as enlarged, the projection of the hippocampus being relatively smaller in comparison with the ventricle."

In antero-posterior skiagrams with one side of the head uppermost the inferior horn is the highest part of the ventricular system, and is therefore well filled. The actual shape of the shadow is somewhat variable, but a crescentic appearance similar to that shown in figure 13b is most common. The concavity of the crescent is directed downwards as well as inwards (Fig. 58f). The body is the most lateral (or, in the posture under consideration, the highest) part. The density and size of the shadow cast by the tip of the ventricle is variable. In figure 58f it is seen extending downwards and medially from the body. The contrast shown in figure 47 between the two temporal horns of a patient in whom a homonymous hemianopia was found, suggests a vascular lesion as the pathological basis.

Choroid plexuses

As previously indicated the choroid plexus protrudes into each lateral ventricle from the velum interpositum in the choroidal fissure. Corresponding to the extent of the velum interpositum, the plexus extends through the body of the ventricle, the trigonum and the temporal horn, from the interventricular foramen nearly to the tip of the temporal horn. It does not extend into the frontal and occipital horns. It follows the floor of the body, and turns over the pulvinar of the thalamus on the anterior wall of the trigonum, into the supracornual cleft of the temporal horn. As it turns over the pulvinar it expands into a mass called the glomus. This is the region which may, when calcified, be seen in skiagrams.

In encephalograms the choroid plexuses of the lateral ventricles may often be seen in three views. In lateral films the glomus may be seen as an irregular filling-defect, about 1 cm. in diameter, extending into the trigone from its anterior wall (Fig. 58). When the glomus is large it may be recognized in postero-anterior films (Fig. 58d). In antero-posterior films it may be seen as a small elevation on the floor of the body of the ventricle (Fig. 8c). The choroid plexus of the third ventricle is seen only as a part of the roof of the ventricle. The filling defect which represents the choroid plexus in the lower part of the fourth ventricle has previously been described.

Relation to lobes and dural partitions

The tip of the anterior horn lies just behind the anterior extremity of the genu of the corpus callosum, 3 to 4 cm. posterior to the tip of the frontal lobe (Fig. 48). The lower extremity of the central sulcus is situated in more or less the same coronal plane as the foramen of Monro. The upper extremity of the central sulcus is situated above the trigonum or the posterior part of the body of the ventricles. The part of the body behind the central sulcus, and the upper part of the trigone, are situated in the parietal lobe. The lower part of the trigone is in the temporal lobe. The posterior part of the trigone extends to the junction of parietal and occipital lobes.

From its attachment to the crista galli the free edge of the falx cerebri curves round the genu of the corpus callosum, a few mm. in front of it. It then extends backwards above the body of the corpus callosum, and near the splenium it is attached to the superior surface of the tentorium. At this point the vena magna cerebri passes into the dura to join the inferior sagittal sinus and form the straight sinus. The tips of the anterior horns lie just behind the coronal plane through the anterior free edge of the falx. Posteriorly the upper parts of the trigones lie opposite the free edge. The exact relationship varies; the greater part of the trigone may lie anterior or posterior to this edge. The lower part of the trigone is usually below the highest point of the tentorium.

The importance of the downward tent-like slope of the tentorium, and of the anatomical relationships of the incisura tentorii has recently been emphasized by Jefferson (1938). The free edge of the tentorium projects into the ambient cistern which surrounds the brain stem. The infero-medial surfaces of the temporal lobes rest upon the upper surface of the tentorium, and the uncus may extend slightly medial to its free edge. Herniation of brain substance through the incisura tentorii was first described by Meyer (1920). Jefferson points out that pressure from above will cause the temporal lobes to slide away from the midline down the inclined plane provided by the tentorium. If, however, the bulk of the temporal lobe is increased, that part near the incisura (the uncus) will overhang the free edge of the tentorium and may press against the mid-brain and herniate into the posterior fossa. A tumour in the temporal lobe is the lesion most likely to produce such herniation.

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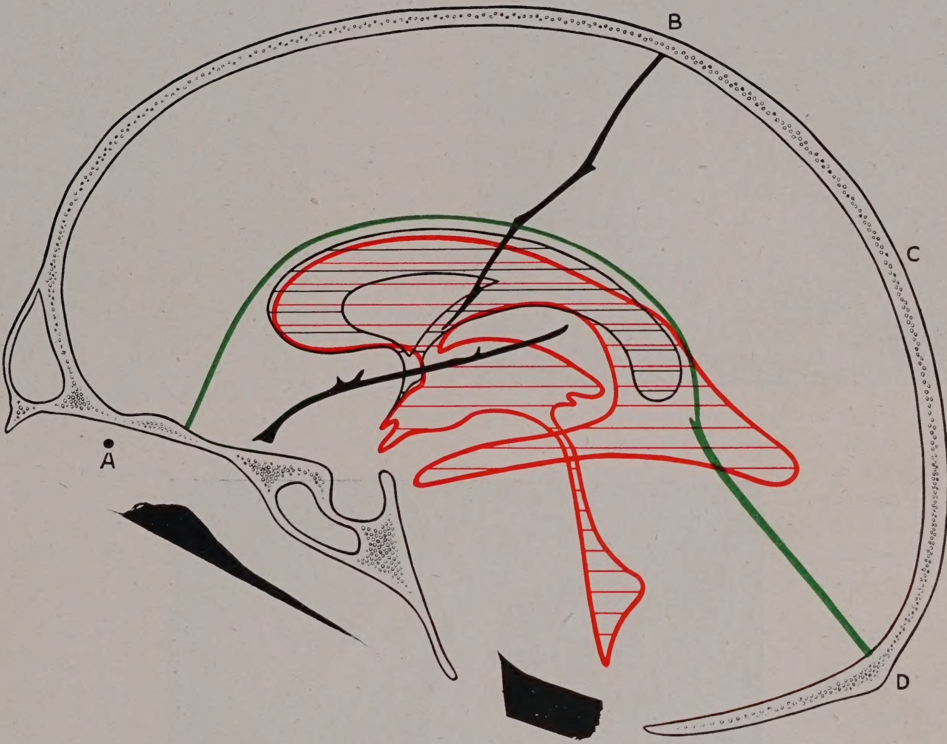

Fig. 48—The relations of the ventricles (red) to the corpus callosum and fornix, the Sylvian fissure and central sulcus of Rolando (black), and the falx and tentorium in the midline (green): A, zygomatic process of the frontal bone; B, a point half-an-inch behind the mid-point between the glabella and the inion (D). Here the central sulcus makes an angle of sixty-seven degrees with the horizontal plane (Chiene); C, the three-quarter point betwen the glabella and the inion. The posterior horizontal limb of the lateral fissure of Sylvius underlies part of the line joining A and C.

To face page 64.

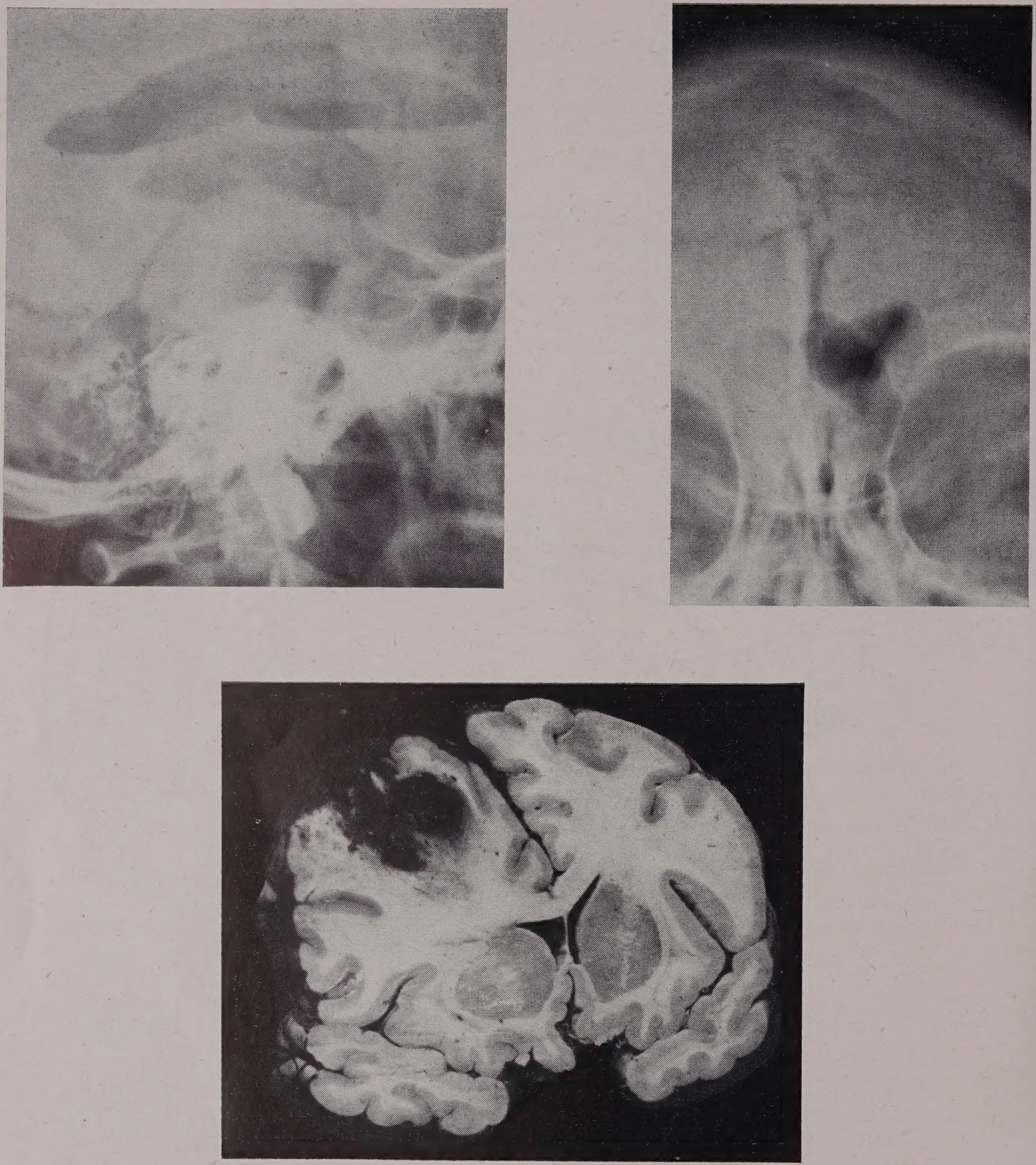

Fig. 49—Findings in a patient (M.A.) with a right frontal glioma—(a) lateral skiagrams with head erect (fifteen c.cm. of air). The right ventricle is depressed and contains only a small quantity of air. Note the column of air between the spinal theca and the fourth ventricle; (b) antero-posterior skiagram, brow up (20 c.cm. of air). The shadow of air in the right anterior horn resembles a frontal sinus. Note the displacement and convexity of the longitudinal cerebral fissure towards the left side; (c) showing the location of the cavity after removal of the tumour.

To face page 65.

Failure to fill one ventricle

In some cases in the series air entered only one lateral ventricle during filling and, in two, it proved impossible to transfer air from one ventricle to the other. In one case the left lateral ventricle was well filled, but only a very small quantity of air entered the right and the quantity was not increased by manipulation. After air was introduced directly into both lateral ventricles these were found to be equal in size, but unfortunately the problem of communication between the ventricles was not studied. There was no evidence of a pathological lesion.

In one patient air at first entered one ventricle and only commenced to enter the other towards the end of the injection of 30 c.cm. of air. Although the ventricles were large, it proved difficult to distribute the air equally, and impossible, even after prolonged manipulation, to effect its complete transference. This difficulty in filling one ventricle does not necessarily indicate a pathological lesion, but may depend upon some relatively unimportant anatomical variation in the interventricular foramina. It is important, however, to realize that this state of affairs, occurring without displacement of the filled ventricle, cannot be taken as disproving the presence of a neoplasm.

M.A., a woman of fifty-seven years, apparently previously well, collapsed and was admitted to hospital unconscious and in status epilepticus. The fits began with clonic spasm of the left hand and arm, and spread to the left side of the face (with less severe twitching of the face on the right side) and occasionally to the left lower limb. The fits ceased after the injection of sodium phenobarbital. When she recovered consciousness the left arm was completely paralyzed and the left side of the face and left lower limb were weak. There was marked loss of discriminative sensibility on the left side. The blood pressure was 170/100. The cerebrospinal fluid was under an initial pressure of 100 mm. and was normal on examination. Skiagrams of the skull were normal. Within four days the abnormal neurological signs had almost disappeared, but fifteen days later the left side of the body was again found to be paralyzed and the mentality was markedly impaired.

Encephalography was performed seven days later. The initial pressure was normal. During the introduction of 15 c.cm. of air there was free passage into the left lateral ventricle which in postero-anterior views appeared to be normal in size, shape and position. A lateral view, taken with the head erect (Fig. 49a) showed a small quantity of air, with a smooth and straight upper edge, in the right ventricle just above the position of the interventricular foramen. This indicated that the roof of the right lateral ventricle was displaced downwards. Five c.cm. were now introduced with the head in the extended posture and a series of films was taken with the patient lying down. In the antero-posterior view the left ventricle again appeared to be normal and undisplaced (Fig. 49b). A very faint shadow could be seen representing the left frontal horn. Air which had entered the great longitudinal fissure, lying between one of the hemispheres and the falx, showed as a narrow curved streak with its convexity displaced towards the left. This was also seen in the inter-axial and postero-anterior films. In spite of prolonged attempts no further air could be transferred to the left ventricle, there being insufficient air to outline it in lateral views. At operation a tumour was found to be presenting on the surface in front of the upper part of the pre-central gyrus. A reddish, white, soft mass about 4 cm. in diameter was removed. On section it proved to be a glioblastoma multiforme. The patient died two days later. A coronal section of the brain is shown in figure 49c. Oedema of the right hemisphere had now caused considerable displacement of the ventricles to the left.

This case has been described in detail for two reasons. Firstly, it may be stated that if one ventricle does not fill, a normal ventricle on the other side is not proof of the absence of a space-filling lesion. Secondly, it affords evidence of a localized displacement of a rigid membranous partition—a displacement of almost the same degree as that of the ventricle in a downward direction. There was apparently no medial displacement of the ventricle and the intracranial pressure was not increased. The pressure in the region of the tumour must therefore be higher than elsewhere in the brain, the pressure decreasing along more or less radial lines from the tumour.

It is interesting that, although a small quantity of air entered the right ventricle during filling, none could subsequently be transferred to it, apparently due to blockage of the interventricular foramen. This same inability to increase the amount of air upon the abnormal side when the patient was recumbent (although some had entered during filling) was noticed in two other patients suffering from gliomata.

Deformation by neoplasm

The displacements of the ventricular shadows produced by space-filling lesions in the cerebral hemispheres have been concisely described by Lysholm (1938) and by Stone and Schulze (1938). In this series a total number of two hundred and eight patients have been investigated, and neoplasm proved to be present in fourteen. Since this series was completed less patients have been subjected to encephalography, but a much higher proportion of investigations have revealed the presence of neoplasms. These cases represent only a small proportion of those treated for neoplasm, for if the diagnosis was obvious further investigation was avoided. When the intracranial pressure was raised, ventriculography was used only if evidence of localization were necessary. The material provided by this series of encephalographies is too small to serve as the basis for a dissertation upon localization. A few random remarks bearing upon the problem may, however, be permissible at this juncture.

The encephalographic picture last described (Fig. 49) is evidence that the increase in pressure caused by a tumour is greatest in the tumour itself, and diminishes in progressively widening circles around it. A similar phenomenon was seen in another patient in whom a subcortical glioma in the temporal lobe caused expansion of the temporal bone, with an actual central hiatus in the bone. There was also considerable ventricular displacement at the time of death. Cairns (1939) has drawn attention to the fact that "the rise of intracranial pressure occasioned by a tumour may be greater in the region of the tumour than in other parts of the cranial cavity," greater even than in other parts of the same dural compartment. In most instances the dura-compartmented skull acts as a rigid barrier, so that if expansion commences in one compartment it must occur at the expanse of fluid contents—cerebrospinal fluid or blood—or by displacement towards a region of lesser pressure, and, ultimately through the foramen magnum. However, the picture of pure centrifugal expansion of the tumour itself is modified by other factors—oedema surrounding the tumour, the effect upon the circulation of cerebrospinal fluid, and the presence of dural partitions. Gross oedema may involve the whole of a hemisphere in which a small tumour is situated, and this may produce a misleading ventricular picture. When there is blockage of an interventricular foramen the pressure within the ventricle will increase, and if there is tumour tissue impacted in the foramen this increase may be greater than in the tumour itself.

The pressure in the dural compartment in which these conditions exist will be greater than in other regions within the skull. Increase in bulk of contents of one compartment may result in the herniation of its contents into another, and this in turn may aggravate the condition by causing or increasing obstruction to the flow of cerebrospinal fluid. Herniation may occur from side to side under the falx, or downwards through the incisura tentorii or the foramen magnum. Transit under the falx will, in the early stages, furnish a useful decompressive effect, but herniation through the incisura tentorii and the foramen magnum are of threatening significance because of obstruction to the circulation of cerebrospinal fluid and the compression of mid-brain and medulla. The obstruction to the flow of cerebrospinal fluid through the foramen magnum assumes significance after lumbar puncture, as the reduction of pressure below will result in firmer impaction of the tonsils of the cerebellum, producing greater pressure on the medulla. A similar effect may be produced by lumbar puncture in the presence of incisural herniation. When the intracranial pressure is generally raised, as when the obstruction is in some part of the aqueduct or fourth ventricle, or in the subarachnoid channels leading to the region of absorption along the longitudinal sinus, the conditions are again altered. When compression of the subarachnoid space over one hemisphere is produced by a tumour within this hemisphere, the contralateral ventricle may expand to a greater extent than the ipsilateral, for on this side the greater pressure in the cerebral substance and the space occupied by the tumour may prevent a similar increase. In the cases in which encephalography is performed, however, oedema and increased intracranial pressure are usually absent or slight.

A tumour growing in the neighbourhood of a ventricle may produce local deformity of the ventricle with little general displacement. A tumour in relation to the frontal horn may displace it backwards if near the tip, upwards if below the ventricle, or downwards if above. Both ventricles may be displaced if the tumour is in the middle line, e.g., a glioma of the corpus callosum or a meningioma of the olfactory groove. Similarly other parts of the ventricle may be encroached upon or displaced. A tumour near the vertex will cause downward displacement of the ventricle with blunting of its supero-lateral angle; at a lower level it causes medial displacement. When the tumour is situated towards the base, the supero-lateral angle of the ventricle may become more acute (compare the anterior horns in figures 51 and 50).

In normal specimens there may be asymmetry of the occipital horns, and the anterior wall of one trigone may be situated in front of that of its fellow. When a neoplasm causes obliteration of an occipital horn, there is likely to be displacement of the trigone (Fig. 45). Displacement of any part of the ventricle across the mid-line occurs only in the presence of a neoplasm. Displacement of the temporal horn may be an important indication of the position of a space-filling lesion. Whatever the position, there is a tendency for expansion towards the other dural compartments. This expansion is, for reasons to be mentioned, most evident in the anterior parts of the ventricles. Thus, even when the tumour lies in the occipital lobe, the septum pellucidum may be displaced across the mid-line.

The encroachment upon, and displacement of, the ventricles produced by centrifugal expansion of a tumour could be more readily predicted were there no dural partitions to modify the process. Expanding lesions of the cerebral hemispheres may produce herniation beneath the free margin of the falx cerebri. The correct interpretation of the ventricular abnormalities produced is important in diagnosis. Stone and Schulze (1938) point out that the anterior horns and the third ventricle lie opposite the incisura of the falx and are therefore displaced more readily than the trigones, which lie behind the free edge. The floor of the third ventricle is anchored below by the pituitary stalk and the upper part of the ventricle is therefore more readily displaced than the lower. Lysholm (1938) states that a tumour above the level of the lateral ventricle tends to produce more displacement of the septum pellucidum than of the third ventricle, so that the line formed by these two structures is inclined away from the tumour; whereas, when the tumour is below this level the upper part of the third ventricle suffers the greatest displacement (Fig. 50). The upper part of the line formed by the third ventricle and septum pellucidum curves back towards the side of the tumour. The downward displacement of the roof of the ipsilateral ventricle is due to transit of the ventricle, and of the callosal gyrus above it, under the rigid lower margin of the falx. In antero-posterior views this communicates a characteristic concave or flattened outline to the upper border of the ventricular shadow. The contralateral ventricle may be narrowed and its roof elevated. This deformity is produced by the corpus callosum and septum pellucidum crossing the mid-line. In one coronal section studied, the fibres of the corpus callosum above this contralateral ventricle appeared to be rotated and relaxed by this displacement and bellied upwards by the pressure of the cerebrospinal fluid. If at a later stage, the lower edge of the falx is displaced, narrowing of the ventricle may become marked. A similar effect is seen in figure 49c. In these cases the displacement of the anterior horn may suggest the position of the lesion. In subfrontal tumours the horn is elevated. The influence of small temporal tumours may be slight. The effect of larger swellings have already been discussed. When the tumour is in the Sylvian fissure, or in the lower posterior part of the frontal lobe, the horn may be narrowed.

In figure 50 the medial displacement of the anterior horn is seen to be greater than that of the body, and the shadow of the pineal gland lies nearer the mid-line. The tip of the anterior horn is narrowed. This suggested a neoplasm involving the lower posterior and lateral part of the frontal lobe rather than the temporal lobe. The patient had suffered from three generalized convulsions. For half an hour preceding one of these his mouth filled with saliva. He did not remember any associated olfactory or gustatory experiences. There was some failure of memory and of emotional control. There were no abnormal physical signs. Skiagrams showed that the lesser wing of the sphenoid on the left side was a little thinner than that on the right. At operation a meningioma weighing 84 gm. was removed. This had a broad attachment to the dura in the region of the right pterion and the outer third of the lesser wing of the sphenoid. From this base it narrowed into the region of the Sylvian fissure, and displaced the frontal lobe upwards and inwards, and the temporal lobe downwards and inwards to a much smaller degree.

As Stone and Schulze point out, the posterior portion of the falx extends forwards between the posterior poles of the hemispheres to the region of the trigones. Medial displacement of the trigone will bring it into contact with the free edge of the falx, and may so produce considerable deformity of the ventricle. Bull (1940) draws attention to the frequency of "falx pressure" in subdural haematomas. An example of this deformity is shown in figure 54d.

It may be pointed out, in conclusion, that an accurate knowledge of these various displacements may enable the encephalographer to obtain valuable diagnostic information with the use of a very small amount of air. Sometimes

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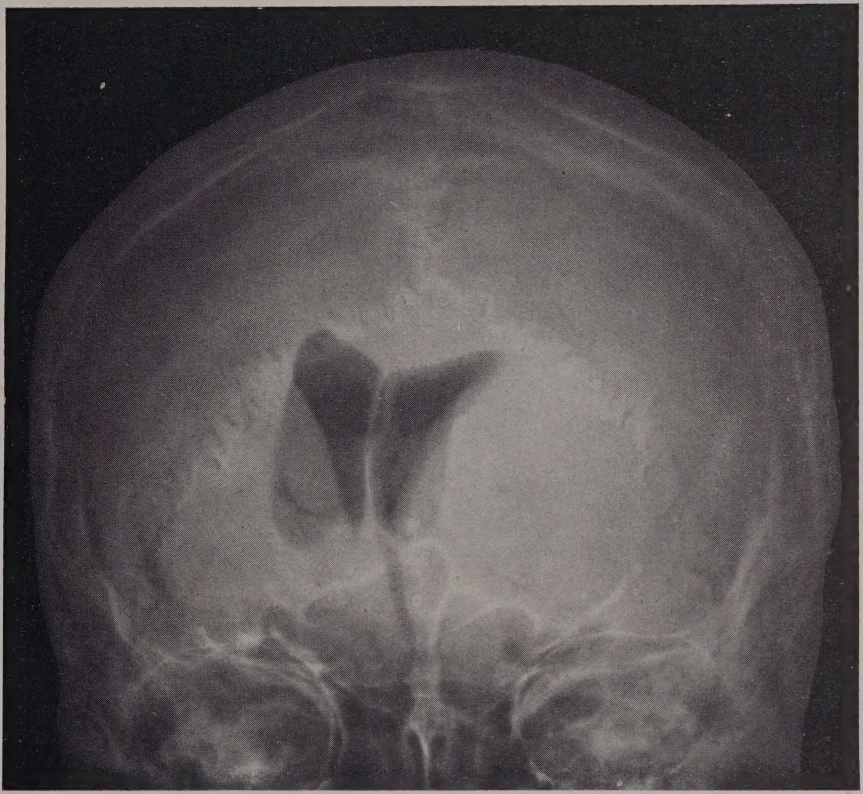

Fig. 50—Characteristic pattern of ventricular displacement produced by a neoplasm situated opposite the anterior part of the opening of the falx. The anterior horn is compressed from side to side and is displaced more than the anterior part of the body, which in turn is displaced more than the calcified pineal gland.

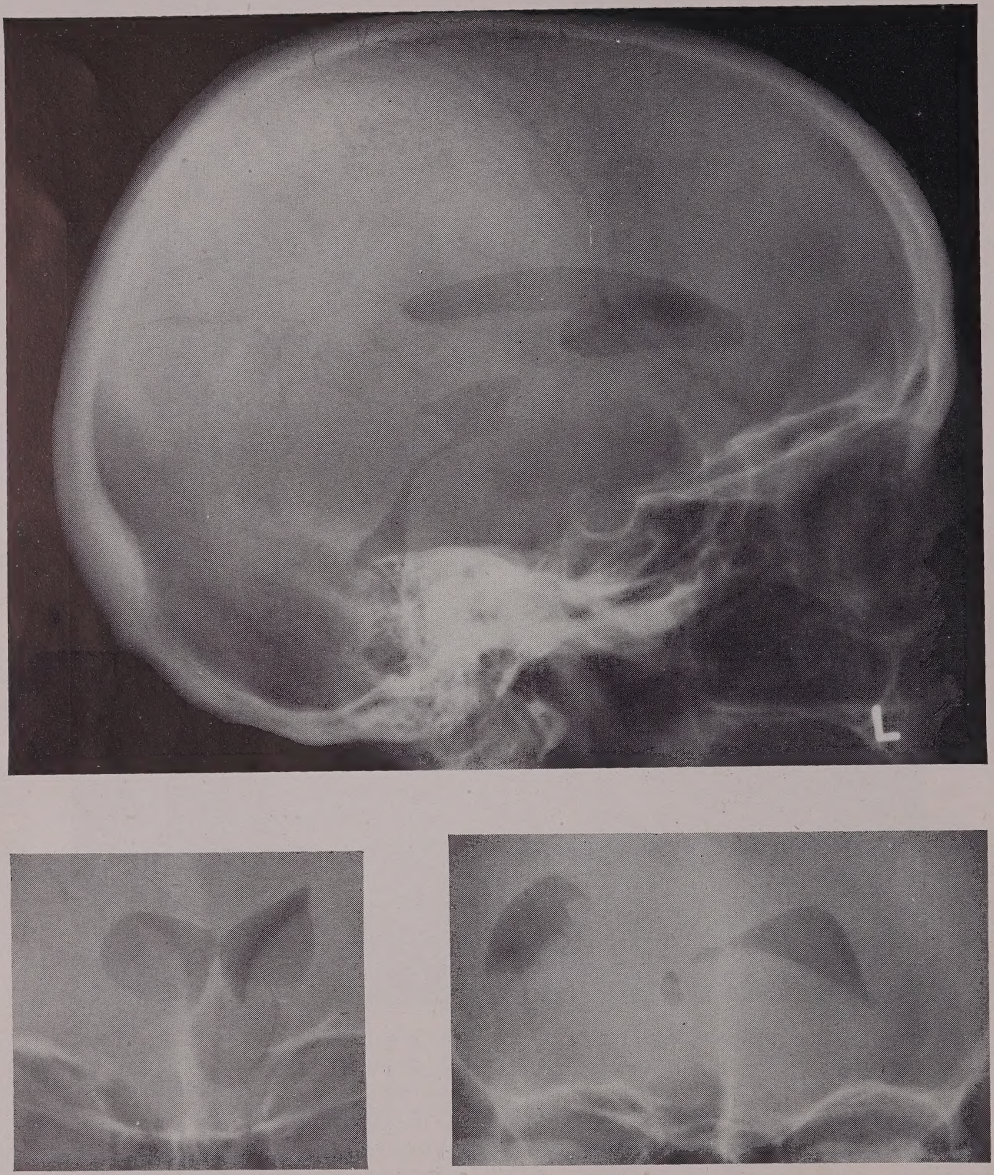

Fig. 51—Lateral, antero-posterior and postero-anterior films, after the injection of eight c.cm. of air, confirming the presence of a space-filling lesion in the upper part of the right parietal lobe.

the lateral films taken during filling show so significant a picture that the filling may be terminated at an early stage. This may add to the safety of the procedure. Figure 51 shows such an initial film. The patient, a woman of forty-two years, suffered from weakness and twitching of the left leg with slight discriminative sensory loss in the left foot. There was no evidence of increased intracranial pressure. Encephalography confirmed the clinical suspicion that there was a tumour in the right parietal region. At operation a parasagittal meningioma weighing 72 gm. was removed.

A high proportion of meningiomas are likely to occur among the tumours localized by this method. As they are of slow growth they tend to produce considerable ventricular displacement before signs of increased intracranial pressure appear. The patients are usually healthy and suffer from focal epilepsy.

Neoplasms without distortion

Encephalograms may show an apparently normal ventricular system although a tumour is present. Gliomata can attain a considerable size, replacing cerebral tissue as they grow, without significantly altering the bulk of tissue, and very large tumours have been found with very little alteration in ventricular form. Gardner and Nichols (1933) refer to two cases (of a series of fifty cases, in thirty-three of which the intracranial pressure was raised) in which the ventricles appeared normal. Hyndman (1938) refers to three patients with cerebral tumours in whom normal ventriculograms were obtained. At operation a frontal astrocytoma was found in one, an occipital angioma in another. Pennybacker and Meadows (1938) describe four cases in which "the ventriculograms showed no lateral displacement of the ventricular system, or any other abnormality in the axial projections, at a time when the tumours had already produced well-marked physical signs. The tumours were all gliomata, two of them astrocytoma and two spongioblastoma. In each case the clinical picture was of a progressive neoplastic lesion." In one patient the ventriculogram was done only five days before death. Autopsy revealed a large tumour in the frontal pole. It is to be noted that these authors refer chiefly to lateral displacements seen in antero-posterior and postero-anterior projections.

The fuller the encephalographic synthesis of the ventricular system, the less likely will be an incorrect diagnosis, but mistakes will continue to occur. In the following three cases (only one belonging to the series of consecutive cases) encephalography was thought to give no evidence of the presence of a neoplasm. In one of these, when reviewed, a small displacement of the temporal horn clearly indicated the position of a neoplasm. In the second there was no indication of the presence of a neoplasm. In the third there was no abnormality in antero-posterior or postero-anterior films.

Q.S., a woman of fifty-four years, suddenly arose from the lunch-table, mumbled something which her husband was unable to understand, and fell to the floor unconscious, vomiting profusely. An hour after the onset her nose bled. On examination the limbs were flaccid, the right plantar response was flexor, the left extensor. She gradually recovered consciousness and complained of severe headache and double vision on looking to the left. There was bruising in the region of the left orbit. Five days later lumbar puncture revealed a yellow fluid under a pressure of 60 mm. It contained 1,800 erythrocytes per c.mm. with an occasional polymorph. The total protein was 45 mg. per cent., and the globulin was not increased. The Wassermann reaction was negative. Sixteen days after the onset she had two attacks in which she heard noises "as if she were going under an anaesthetic" and lost consciousness. She made chewing movements with her lips and jaws. Immediately after each attack the plantar responses were extensor. Later in the day she again noticed double vision. During the succeeding days she complained of headache and stiffness of the neck. She was lethargic and the right arm appeared to be clumsy. Retinoscopy showed slight arteriosclerosis and the blood pressure was 155/90. Fifteen c.cm. of air were introduced by the lumbar route seven weeks after the first attack. There was no lateral displacement of the ventricles, and the diameter of the left ventricle (1·8 cm.) was two mm. less than that of the right. Stereoscopic lateral views revealed no definite abnormality. In review, antero-posterior films with the head in each lateral position (Fig. 52) gave evidence of the lesion, in the form of a small difference between the tips of the temporal horns. At the time, however, it seemed difficult to assess the significance of this, especially as the shadows of the temporal horns appeared to be symmetrical in the lateral views. Later in the day on which encephalography was performed the patient had an attack in which she lost consciousness for a brief interval. During this time her eyes were rotated to the left and both plantar responses were extensor. In the succeeding days she improved considerably, but seven weeks later she became semi-comatose. On examination there was a spastic paresis of the left limbs, and both plantar responses were extensor. The pulse-rate varied between 80 and 90, the blood pressure was 180/100. The cerebrospinal fluid was under an initial pressure of 210 mm. It contained two lymphocytes and one large mononuclear cell per c.mm. Globulin was increased and the protein was 160 mg. per cent. The patient died shortly afterwards. The cause of the symptoms, a glioblastoma multiforme, is illustrated in figure 52c.

In the following case re-examination of adequate encephalograms, when the nature of the lesion was known, revealed no abnormality.

Encephalography was performed six weeks after the onset of attacks in which the patient (J.S.) experienced intermittent sensations of pins and needles in the right hand. During the attacks conversation ceased unless he concentrated, and in writing he formed the letters badly and misspelt words. He also suffered from headaches behind the eyes. He remained moderately well with occasional attacks of loss of consciousness until, thirty-one months later, headache re-developed, and the right arm and leg became powerless and he lost the ability to read. Examination revealed a right-sided homonymous hemianopia and impairment of discriminative sensibility in the right limbs. The pressure of the cerebrospinal fluid was 210 mm. and it contained 70 mg. per cent. of protein. At operation a large, firm astrocytoma was found in the posterior part of the left temporal and parietal lobes and in the occipital lobe. Reviewed even with this knowledge, sagittal and lateral views of the well-filled ventricles revealed no abnormality. It is to be remembered, however, that the investigation was performed very soon after the onset of symptoms. For this reason a repetition of a negative investigation may be wise if the diagnosis does not become certain on clinical grounds.

In the following case antero-posterior and postero-anterior films, made two months before the patient's death from an intracranial neoplasm, revealed no ventricular displacement. The filling, however, was not sufficiently complete to allow of full visualization of the lateral ventricles.

O.G., a man of fifty-one, commenced to suffer from a series of attacks three months before admission to hospital. Twitching began in the left side of the upper lip, and spread first to the left side of the face and then to the index finger and thumb. Such attacks occurred with increasing frequency, until a fortnight later he had three within a period of six hours. After this the left side of his face dropped and a few days later his left hand became useless. He had noticed inability to concentrate, and some confusion of thought. For twenty-four hours he had suffered from severe generalized headache, worse on the right side of the head and increased by coughing or movement.

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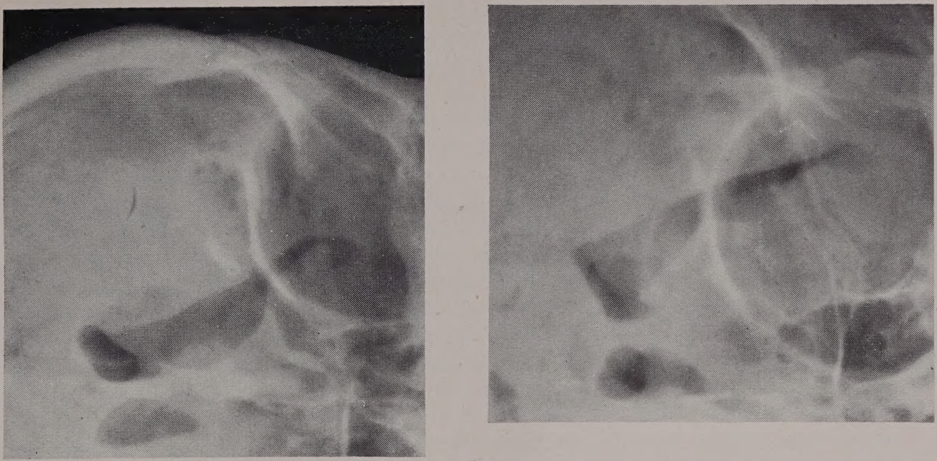

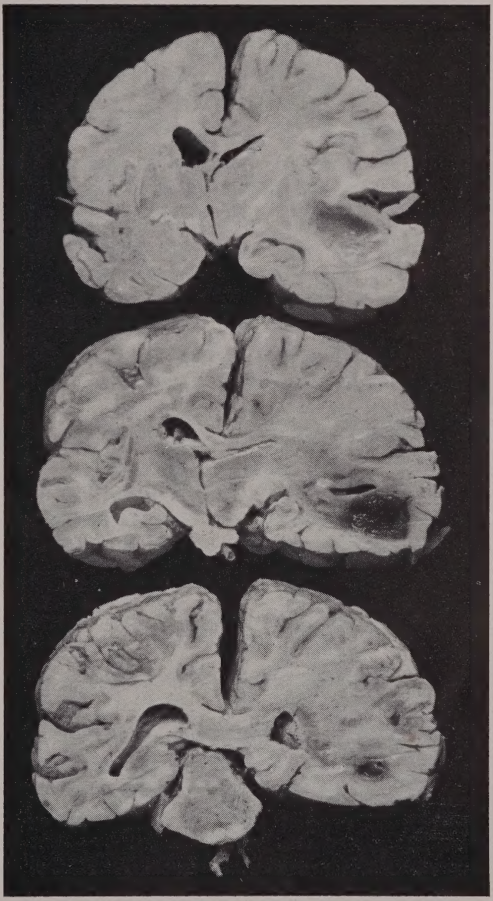

Fig. 52—Alteration in the temporal horn produced by a glioma of the left temporal lobe—(a) postero-anterior film with the right side of the head uppermost; (b) antero-posterior film with the left side of the head uppermost; (c) coronal sections of the brain.

Examination revealed bilateral ptosis and severe left-sided facial weakness. The power of the left arm and hand was slightly reduced. No abnormality of tone was detected. The deep reflexes were equally hyperactive, the abdominal reflexes were equally reduced and the plantar responses were extensor. Superficial sensibility was reduced over the left forearm and hand. Discriminative sensibility was poor on the left side, especially in the hand. There was no papilloedema and no stiffness of the neck. On the day after admission he was drowsy, although there was no slowing of the pulse rate. The pressure of the cerebrospinal fluid was 230 mm. and Quickenstedt's test was normal. The total protein content was 70 mg. per cent.; otherwise the fluid was normal. It was decided that he had a rapidly growing glioma and removal was not attempted. The patient became comatose, and died. At autopsy the whole of the right cerebral hemisphere was much larger than the left, and the ventricles were displaced towards the left. The upper part of the septum pellucidum was displaced more than the lower. The tumour was seen as a greyish-white, firm mass about an inch in diameter, in the lower anterior part of the parietal lobe, half an inch below the surface. Histological examination showed it to be a spongioblastoma unipolare. Encephalography had been performed elsewhere on two occasions, two months and six weeks before death, but no definite abnormality had been detected.

The next case provides another illustration of the co-existence of ventricular shadows which were indistinguishable from normal and a space-filling lesion. It also illustrates the value of visualization of the subarachnoid space, for the absence of filling of an area which normally fills easily supported the clinical diagnosis.

P.S., a woman of forty-six years, awakened one night, three months before investigation, feeling as though the left leg had gone to sleep. This lasted for half an hour. When she was dressing in the morning she found difficulty in putting her foot into a shoe. Two weeks later the left calf muscles began to twitch, and the twitching extended upwards to the hip. Afterwards the lower limb felt dead. Three weeks later an attack of twitching was followed by a feeling of pins and needles which started in her left foot, reached to the hip, and was then felt behind the left ear. Her leg felt normal within an hour. After this, however, the leg seemed rather dead and the foot dragged when she was tired. Subsequently she had four similar attacks and in the last attack the numb feeling extended from the leg up to the shoulder and thence down to the left hand and into the left side of the face.

On examination there was slight weakness of flexion of the left hip and dorsiflexion of the left foot. The left ankle jerk was more active than the right, the abdominal reflexes were absent and the left plantar response was extensor. Superficial contacts with the left lower limb felt "different." The appreciation of movement of the left great toe and the ability to distinguish between single and double contacts were slightly impaired. There was an area of dusky pigmentation over the left side of the forehead and left conjunctiva. The pressure of the cerebrospinal fluid was 130 mm. The fluid was normal, apart from an increase of protein (55 mg. per cent.). The Wassermann reaction was negative.

The introduction of 15 c.c. of air revealed no definite abnormality in the lateral, third and fourth ventricles. The lateral ventricles were normal in size (right 2 cm.; left 1·9 cm.) and were symmetrically disposed in relation to the mid-line. The superolateral angle of the right ventricle was 2 mm. lower than that of the left, but the right side of the skull was slightly flatter than the left. This illustrates the difficulty of interpretation when minor variations are present. Eighty c.c. of air were subsequently introduced into the subarachnoid space under avertin anaesthesia. The patient's head and neck were extended, and the air first passed into the sulci on the medial surface of the hemisphere. The upper part of shadow in the great longitudinal fissure was displaced slightly to the left. Subsequently air outlined the sulci over the frontal poles, occipital lobes and the left parietal lobe. No air extended over the surface of the posterior part of the right frontal lobe and the right parietal lobe, in spite of subsequent posing of the head.

The upper right fronto-parietal region was explored ten days later. The cortical veins were large, the gyri appeared to be flattened and the pia-arachnoid in some of the sulci was gelatinous in appearance and contained some yellow pigment. At the upper extremity of the precentral sulcus an encapsulated bluish-black mass about an inch in diameter was seen. It extended 1¼ in. into the brain and, medially, it reached to the falx. It was thought to be blood clot surrounded by a newly-formed membrane. Microsopic examination proved it to be a melanoma.

The patient died nine days after operation. The pia-arachnoid over the inferior surface of the left frontal lobe had a tesselated brown appearance, and on microscopic examination it was seen to be packed with elongated and polyhedral cells containing melanin. There were numerous other brown areas, and indeed the whole pia-arachnoid had a faintly brown colour. This was due to the presence of smaller numbers of pigmented cells. Over the upper posterior part of the right frontal lobe there were a number of small black areas in the pia-arachnoid. From these malignant cells spread a short distance into the underlying brain tissue. The tumour removed at operation was the only large accumulation to be found, and apparently it had its origin in such a fashion. At its periphery a capsule of fibrous tissue had formed, but malignant cells extended outside its limits into the surrounding brain. There were no melanomas in other organs. The tumour was a melanoma, developing in a patient with diffuse melanomatosis of the pia-arachnoid.

When the presence of a neoplasm is suspected, it is therefore a good rule to fill the subarachnoid space if the ventricles appear to be normal. This decision may be made after viewing the postero-anterior and lateral films taken during the early part of the filling. A limited replacement can then be undertaken without causing the patient too much distress.

In the following case a tumour was found on the opposite side to that suggested by the encephalograms.

C.F., a woman of fifty-two years, commenced to suffer from a series of generalized convulsions during which her head would turn to the right side. Before each of these she was "unable to concentrate her mind on her hand. She could not make her hand do what her mind wanted it to do." She was unable to state whether this affected both hands or only one, and later made contradictory statements as to which hand was affected. She had been aware of difficulty in concentration, and for some little time her friends had been worried by her irritability, loss of memory and uninhibited and irrational conduct. It had been noticed that "her right hand sometimes did not go to the right place when she was picking things up." The only abnormalities on examination were an indefinite left plantar response, and some evidence of deterioration of the highest cerebral faculties. The pressure of the cerebrospinal fluid was 180 mm. and the fluid was normal.

Encephalography was performed two months after the onset of the convulsive attacks. The anterior horn and body were much smaller on the right side than the left (right 1·6 cm., left 2·2 cm.). The right trigone was much smaller and its anterior wall was situated 1·2 cm. further forward than that on the left. The right occipital horn was almost absent, the left well developed. The septum pellucidum was in the mid-line. It was believed that these findings gave evidence of a right-sided neoplasm.

The patient refused operation. Subsequently she began to suffer from attacks of headache and vomiting. She complained of "queer blackouts in which things seemed to go out of focus and move." Examination six months after the initial investigation revealed papilloedema and a variable impairment of discriminative sensibility in the right hand. The pressure of the cerebrospinal fluid was 370 mm., the protein 40 mg. per cent. During an attempt at ventriculography the needle on the left side entered a cyst at a depth of 3 cm. Dark brown fluid squirted out. An osteoplastic flap was made and a soft tumour, adherent to the dura, was found in the upper posterior part of the left parietal lobe. The small size of the whole of the right ventricle suggests that this ventricle was congenitally smaller than the left. It is possible that there was a second tumour on the right side, but certainly the tumour which was producing the epilepsy gave no sign on encephalography.

The recognition of the presence of a neoplasm in cases where the intracranial pressure is not raised becomes still more difficult when it is realized that there may be considerable disparity between the lateral ventricles in the absence of a neoplasm. As will be shown later, asymmetry may indicate the presence of a pathological lesion, or merely an anatomical variation. Degenerative lesions may cause dilatation of one or both lateral ventricles and the differentiation from neoplasm may not always be easy. In the following case encephalography revealed dilatation of both ventricles, the reason for which was not correctly diagnosed until the brain was examined at autopsy.

L.H.G., a man of fifty-four, was in a confused state of mind on admission to hospital. He complained of headache and stated that he had been knocked off his bicycle by a closing railway gate during the afternoon. His wife stated, however, that he had been knocked over by a motor-car on the previous day and was brought home in a very confused state. The accident which he described had occurred three weeks before and since then he had complained of headaches and giddy turns, and he had vomited on a number of occasions. His memory had been failing for some months. Beyond a reduction of his highest cerebral functions there were no abnormal physical signs. The pulse rate was 84, the blood pressure 130/90. Two days after admission the pressure of the cerebrospinal fluid was 300 mm. The fluid was normal on examination. The Wassermann reaction was negative in blood and cerebrospinal fluid. Skiagrams revealed a small localized depression in the left frontal region, apparently due to an old injury. His fluid intake was reduced and he was given enemata of a concentrated solution of magnesium sulphate twice daily. Although the pulse rate was sometimes as low as 46, the pressure of the cerebrospinal fluid was 62 mm. a week after admission, and 100 mm. a week later. On discharge from hospital he was well and free from headaches, although he appeared to be mentally reduced. He was readmitted to hospital four months later. He stated that he fell over frequently for "he gets too fast for himself." His memory was impaired and his wife stated that he lived more or less in the past and kept asking where his father (who died twenty-five years before) had gone. Physical examination revealed no abnormality.

Encephalography was performed and the pressure of cerebrospinal fluid noted to be low. The air passed rapidly through the ventricular system. The fourth ventricle appeared to be normal. The third ventricle was only faintly seen in lateral views and appeared to be of normal shape. In a postero-anterior view taken during filling the ventricle measured 6 mm. in width. The lateral ventricles were dilated. The width of the right anterior horn was 3·2 cm., that of the left 3 cm. The trigones and temporal horns suffered even greater dilatation. It was noted that the projection of the thalamus into the right lateral ventricle was unusually marked. The septum pellucidum was situated about 2 mm. to the left of the mid-line. The significance of certain of these appearances was not correctly assessed and a diagnosis of cerebral atrophy was made. The initial high pressure was assumed to be due to cerebral oedema following cranial trauma. The patient was then transferred to another hospital, where he died three months later with symptoms suggesting bronchopneumonia and medullary failure.

On the surface of the brain, the gyri were seen to be flattened and the sulci narrowed. The floor of the third ventricle and the lamina terminalis appeared to be bulbous and thickened. The left lateral wall of the ventricle was formed by tumour, which displaced the ventricle to the right side and reduced its width to a narrow slit. The interventricular foramina were unobstructed. Both lateral ventricles were dilated. The tumour was seen below the anterior two-thirds of the body of the right lateral ventricle. It replaced most of the thalamus and compressed and infiltrated the internal capsule. Below, where it infiltrated the hypothalamus, it was white and firm. In other regions it was softer with some area of necrosis and haemorrhage. It proved to be a cellular type of astrocytoma.

The case has been reported in detail because it teaches some important lessons. It was thought likely that dilatation of the lateral ventricle was due to cortical atrophy because the lateral ventricles filled very rapidly during encephalography. This seemed to imply that there was no obstruction to the outflow from the ventricles such as would produce hydrocephalus. That the pressure of the cerebrospinal fluid was low seemed to support this contention. But the conditions found during encephalography are not necessarily those pertaining during the whole clinical course of the disease. A block in some part of the ventricular system may be transient and perhaps recurrent, and the intracranial pressure may be very variable. Oedema surrounding a tumour, or necrosis or haemorrhage within it, may cause such variations. Early in the clinical course in this case there was manometric evidence of a high intracranial pressure. Had this been given due consideration the slight displacement of the septum pellucidum, the prominence of the right thalamus, and the relatively smaller dilatation of the anterior horns, would have indicated the correct diagnosis.

It also indicates the danger which may beset the examiner during moments of loose thinking. The encephalographic evidence may be made to fit into a preconceived notion of the diagnosis. It is easy to explain away small points, but this may not always be wise. The erroneous diagnosis might have been avoided had an attempt been made to fill the general subarachnoid space. It is probable that no air would accumulate in the sulci, but this might have been ascribed to arachnoiditis.

Such experiences challenge one's belief in the value of encephalography in the early diagnosis of intracranial neoplasm. Indeed, when considering the individual patient, the author cannot rid his mind of the thought that attempts at early diagnosis may not always be in the patient's best interest. He is asked to cease work at a time when he may be economically efficient, and to submit himself to an investigation which may give indefinite results, or lead to operation, after which he may be less able to work than before. If there is impairment of cerebral function, or increased intracranial pressure, operation is necessary, and if the tumour is removable the result may be a brilliant success. But in many early cases the investigation may provide results which are so difficult of interpretation as to lead to error. If the tumour is a glioma the medical attendant may sometimes regret that the operation was not deferred until more sombre symptoms appeared. Many factors must be considered in making the decision in each case, and with all care it is not always possible to decide what will be the best course of action.

Post-traumatic conditions

Very peculiar clinical pictures may be produced by subdural haematomas, and in some cases there is no history of trauma. If the intracranial pressure

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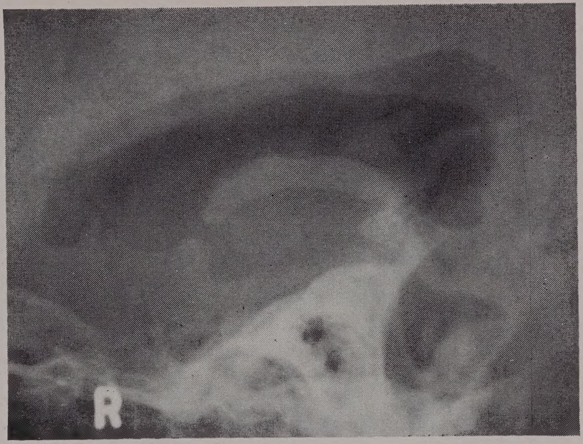
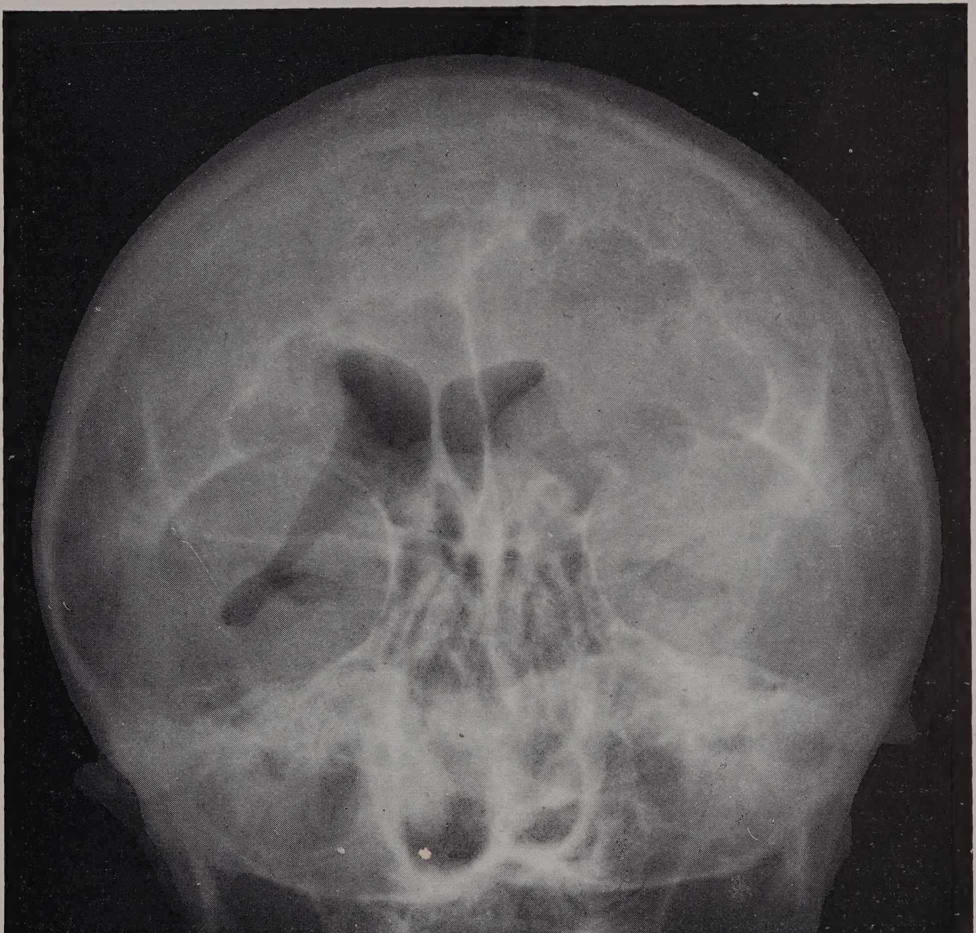
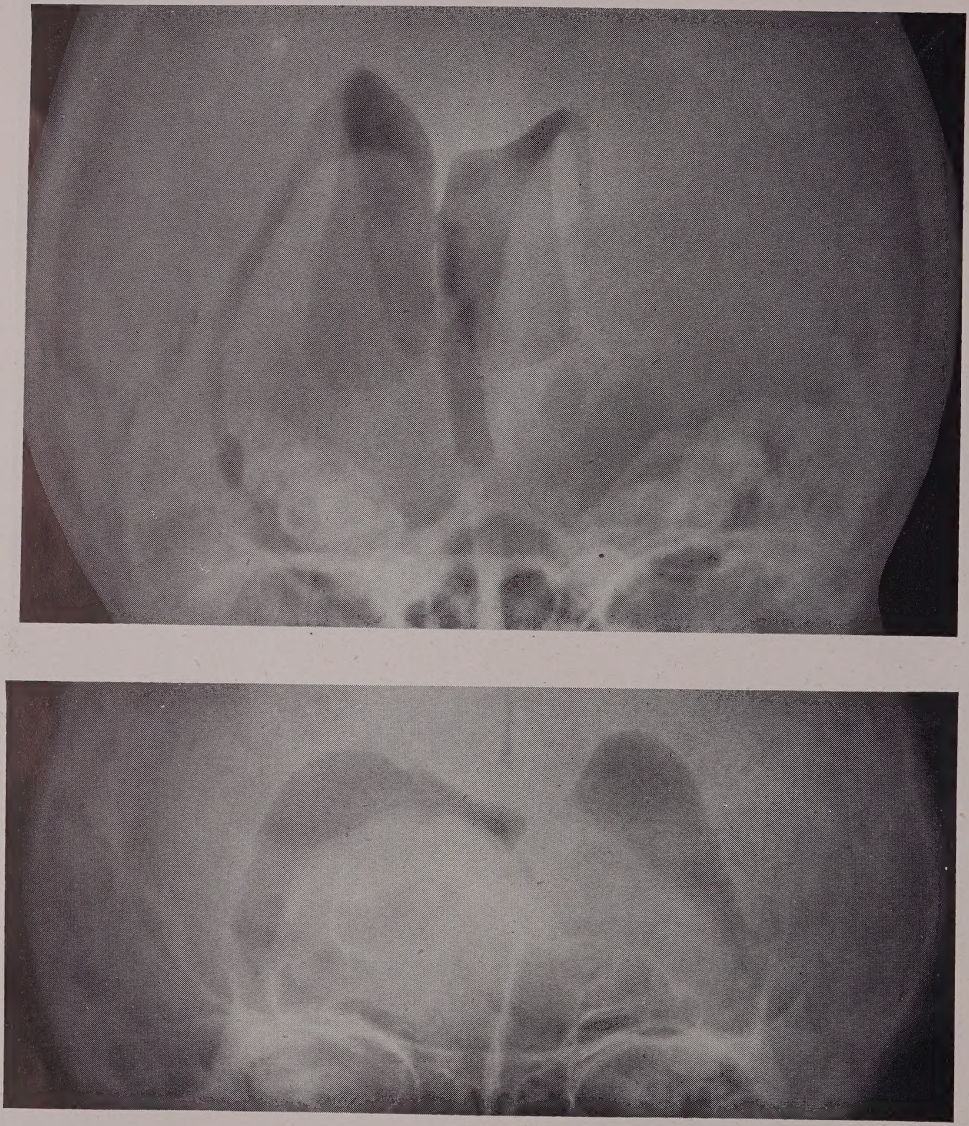
Fig. 53—The ventricular displacement produced by a subdural haematoma over the left frontal and parietal lobes—(a) lateral skiagram with head erect. The left lateral ventricle is depressed; (b) antero-posterior skiagram with brow uppermost. (See Fig. 53c, d, overleaf.)







(c) Inter-axial antero-posterior skiagram with brow uppermost; (d) postero-anterior skiagram with occiput uppermost.

To face page 75.

is low encephalography may be used, and may be responsible for the recognition of a curable condition. If the haematoma is in an unusual position encephalography will be of very great value in determining the site of operation. If it be in the usual location, the haematoma will tend to displace the whole lateral ventricle towards the opening in the falx.

L.W., a man of fifty-eight years, was admitted to hospital in a drowsy state. He could be roused to answer simple questions, but his orientation in time and place was defective and his attention could be held only with difficulty. His wife stated that for six months he had complained of slight headaches. When he had a headache he seemed stupid. Eleven days before admission the frontal headache became very severe, and radiated to the occipital region. He became drowsy and vomited occasionally. His conversation became irrational and while attempting to go to work he fell off his cycle several times. There was no history of injury. Examination revealed weakness of the left arm and leg. The deep reflexes were equally active, the abdominal reflexes were absent and both plantar responses were abnormal, the left being more frankly extensor than the right. The blood pressure was 180/96, and arteriosclerotic retinitis was present. The cerebrospinal fluid was under a pressure of 85 mm. and was faintly yellow, containing 14 lymphocytes and 1 polymorph per c.mm. The total protein was 55 mg. per cent.; the globulin not being increased. The colloidal gold test was normal. The Wassermann reaction was negative in blood and cerebrospinal fluid. The clinical state improved with rest in bed. Encephalography was performed a week after admission to hospital. The left ventricle was depressed throughout its length (Fig. 53) and the ventricular system was displaced to the right, the septum pellucidum more than the third ventricle (Fig. 53b). The depression and indentation of the posterior part of the roof of the body of the left ventricle, and the deformity produced in the trigone as the ventricle was thrust under the falx is seen (Fig. 53a, c, d). The left temporal horn also appeared to be displaced medially. The transverse diameter of the temporal horn, measured in lateral views, was 3 mm. less on the left side than on the right. The patient was operated upon, and a large subdural haematoma, surrounded by a well-formed capsule, was removed after incising the dura over the left hemisphere.

Displacement of the whole ventricle in the manner described is suggestive of a large lesion surrounding the whole ventricle. A later experience showed that uniform downward displacement of the anterior horn, body and occipital horn could also be produced by a temporal neoplasm. In this case the intracranial pressure was low. The characteristic curve of the septum pellucidum and third ventricle served to localize the lesion. It is also to be remembered that alteration in the size and shape of the whole ventricle may be produced by cerebral oedema (whether following upon an injury or associated with a neoplasm) or by a large diffuse glioma. Additional information might be gained by outlining the cerebral subarachnoid space, but when there is massive displacement of the ventricle due to causes other than haematoma, the pressure is usually high, so that ventriculography is used.

In the following case a clinical diagnosis of neoplasm was made, but the ventricular picture was of the same type as in the preceding patient.

Six days before admission to hospital a patient of forty-seven (H.R.) fainted while he was attempting to reach a lavatory in the city. After the attack, failure of memory was apparent, drowsiness became profound, and there was occasional incontinence of urine. His wife stated that he had been drowsy and sleepy for about three months and that he had suffered from intermittent pains in the back of the head for the same period. He had been able to continue his work as an inspector of railway bridges. Examination revealed marked dementia, blurring of the edges of the right optic disc, and an equivocal left plantar response. Subsequently bilateral reflex grasping was noted. The pressure of the cerebrospinal fluid was 240 mm. and the fluid was normal. The Wassermann reaction of the blood was weakly positive. Ventriculography was performed thirteen days after his initial attack. The whole of the right ventricle was displaced to the left side and downwards (Fig. 54) and the indentation produced by the falx in the posterior part of the ventricle could be seen. There appears to be no definite difference between the films in this case and in that last described.

A fronto-parietal exploration was undertaken but the only abnormality seen was widening of the gyri. At autopsy the patient was found to have a small astrocytoma in the upper posterior part of the right frontal lobe (Fig. 54e). The remainder of the hemisphere was swollen with oedema. The occipital horn was absent on the right side and very large on the left. There was a coarse form of granular ependymitis over the floor of the body of each lateral ventricle.

In our usual practice cases of suspected subdural haematoma are not subjected to encephalography. Bilateral trephining in the parasagittal region is undertaken and if blood clot is not encountered ventriculography is performed. Three cases have recently been seen in which the haematoma was situated in relation to the temporal pole.

Von Storch and Munro (1938) provide an important analysis of thirty-five cases of subdural haematoma, in thirty-two of which encephalography was performed. They describe the variations from the normal, and conclude:

> Ordinary cranial roentgenography is of little value in the diagnosis of subdural haematoma. Demonstration of a pineal shift following cranial trauma merely suggests the presence of a mass which may or may not be a clot. Encephalography is rarely diagnostic of subdural hematomas, and then only in cases with large chronic clots. The value of encephalography in the diagnosis of fluid hematomas appears to be negligible. Until further information is available it is unwise to lay too much stress upon the presence of unencysted subdural air as an indication of the presence of a subdural hematoma. On the other hand, it has been demonstrated that encephalography is a valuable adjunct in the diagnosis of thin, solid, subdural hematomas. It is in such cases, in which the history and examination are often inconclusive, that an experienced encephalographist may offer invaluable assistance to the neurosurgeon. In the final analysis we continue to believe that a *definite* "diagnosis of subdural haemorrhage can be made only by exploration."

An important contribution has recently been made by Bull (1940). He believes that encephalograms show constant features in cases of subdural haematoma (except in bilateral and atypical cases). In his series of eighteen cases, twelve showed a remarkable similarity of the mode of displacement of the whole lateral ventricle towards the opposite side.

Although the author's experience is insufficient to evaluate the accuracy of diagnosis it may be said in conclusion that gross displacement of the whole ventricle in the manner described is very suggestive of the presence of an extensive lesion, and a haematoma is the commonest cause when the intracranial pressure is low. If the pressure is high oedema, or a large tumour, may produce a similar appearance.

Statistics suggest the epilepsy is much more frequent after compound fractures of the skull than after other forms of head injury. Many cases are seen, however, in which the onset of epilepsy follows head injuries of less severe types. In these instances the encephalograms may reveal no definite abnormality, yet it is difficult to escape the conclusion that, in some at least, the epilepsy is due to the head injury.

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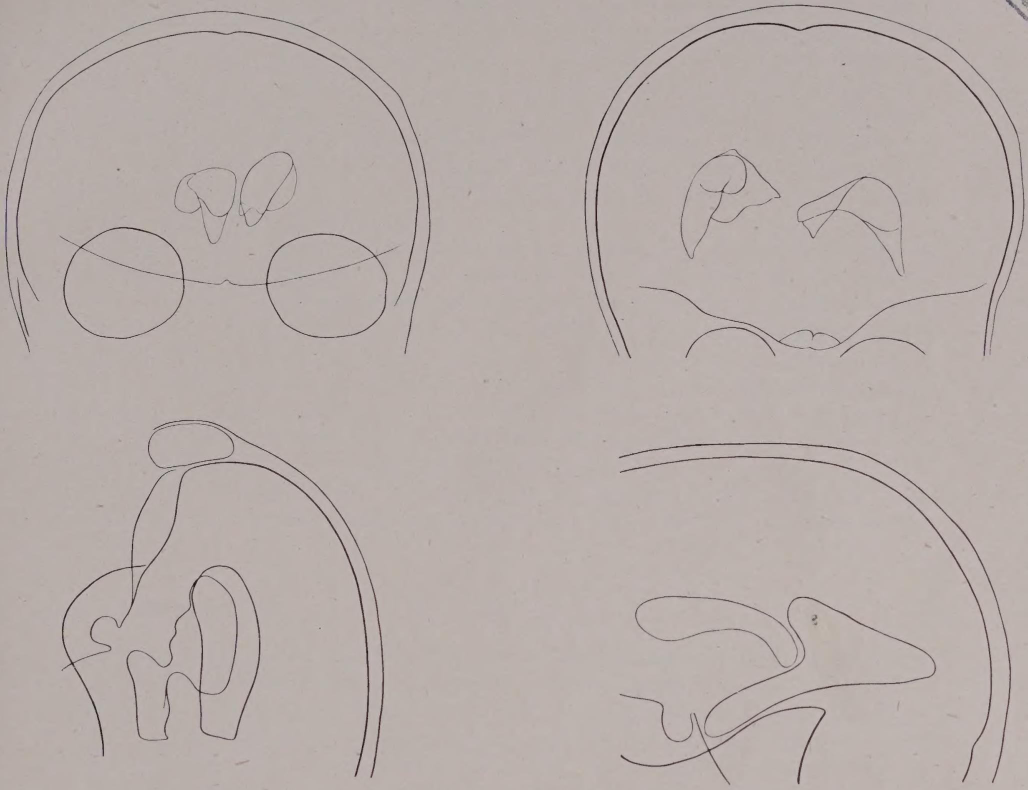

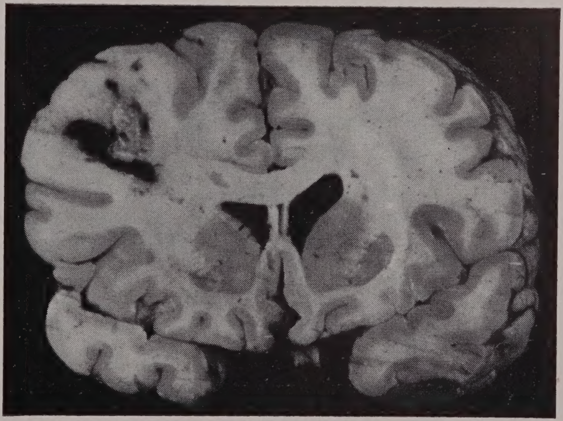

Fig. 54—Gross displacement of the right lateral ventricle, produced by oedema around a small tumour, as shown by ventriculography. It is difficult to distinguish this displacement from that produced by a subdural haematoma—(a) tracing of antero-posterior film, brow uppermost; (b) postero-anterior view, occiput uppermost; (c) lateral view, brow uppermost; (d) lateral view, left side of head uppermost. Air is seen in the large trigone and temporal horn on the left side and in the anterior horn, body and part of the trigone of the right ventricle; (e) coronal section of brain showing the tumour. It measured only 2·5 cm. from front to back.

To face page 76.

Foerster (1924) noted that "wandering of the ventricle" may occur towards the side of an old traumatic lesion. Penfield (1927) showed that this was due to contraction of a connective tissue cicatrix pulling the vaso-astral framework of the brain towards the region of meningeal adhesions. Such a condition may cause epilepsy. Together Foerster and Penfield (1930) advocated the complete excision of such scars in the treatment of post-traumatic epilepsy. Recently Chao Yi-cheng, Humphreys and Penfield (1940) have shown that adhesions can be prevented by the application of amnioplastin to the surface of the brain. Thus Penfield has been associated with the recognition of the fully-developed condition, its pathological study, removal, and finally its prevention.

Because of the distortion produced in the ventricles, encephalography is of value in the recognition of this condition. However, just as a neoplasm can co-exist with a normal ventricular picture, so also may a cerebral scar. In one case a scar involving almost the whole of one frontal lobe caused no abnormality of the ventricular picture. The obliteration of subarachnoid pathways thus becomes of considerable importance in the encephalographic diagnosis of these conditions. In several patients who have sustained a compound fracture of the frontal bone the ventricles have been found to be within normal limits, yet it proved impossible to fill the sulci over the convexity of the frontal lobes. The sulci of the medial surface may fill and the lateral and antero-posterior skiagrams then present a remarkable contrast.

Size of the ventricles

A simple method of recording the size of the lateral ventricles is of value for purposes of comparison and record. The diameter most suitable for measurement is the greatest width of the ventricle opposite the interventricular foramen. The rule is placed just below, and almost parallel with, the root of the ventricle, and the maximum width of the triangle corresponding to the posterior part of the anterior horn is measured. Anatomically this corresponds to the distance between the upper part of the septum pellucidum and the lateral angle, above the caudate nucleus (Fig. 42). The measurement is easily made and allows a direct comparison of the size of the ventricles. Other measurements may serve for confirmation, but are seldom necessary. Accurate comparative measurement of the trigones is more difficult, and in apparently normal cases the trigones are more frequently asymmetrical than the anterior horns or bodies. In cases with expansion of a part of the ventricle, or with hydrocephalus, the measurement advocated is not an accurate index of size. When there is increased pressure within the ventricle, the body and the posterior part of the anterior horn expand chiefly in the lower part of the lateral wall, pushing the caudate nucleus laterally, so that in cross-section the body becomes more circular.

With varying quantities of air, the diameter described shows very little change. This will not hold when the pressure within the ventricle is greatly increased, and the air is introduced directly into the ventricles. That it is a stable measurement in the cases in which encephalography is practiced was demonstrated by a series of investigations performed at intervals on one patient. A man of forty years developed right-sided sensory and motor epilepsy. Maniacal outbursts occurred from time to time until progressive dementia necessitated permanent certification. The only other physical sign noted was a variability in the activity of the deep and abdominal reflexes. Encephalography was performed on three occasions, ventriculography once. The results are set out in figure 55.

As the available series contains no normal patient it is impossible to state the normal transverse diameter of the ventricle. In a series of ninety adults the measurement described varied between 1·2 and 3·5 cm., the greatest number of cases being distributed between 1·5 and 2·6 cm., with a peak at 2 cm. (Fig. 56). It is not known whether ventricular disparity is necessarily of pathological significance, but it is most probable that inequality may exist in normal people. In some cases where the ventricles were unequal, the skull was asymmetrical. This was most obvious in cases of porencephaly where a large ventricle was associated with retarded expansion of one side of the skull. In some cases, however, the side of the skull on the side of the small ventricle was obviously flattened and of lesser cubic capacity than the opposite side. In such cases the septum pellucidum was sometimes also deviated towards the small side of the skull, suggesting that the whole hemisphere was smaller on this side, probably as the result of causes active during the developmental period. When the degree of asymmetry of the skull is small it is difficult to decide whether the cubic content of one side is greater than that of the other, and in any case, this is probably only a rough indication of the state of development of the contained cerebral hemispheres.

In a consecutive series of one hundred cases subjected to encephalography for whatever cause, the transverse diameters of the ventricles were equal in twenty-seven cases and unequal in seventy-three. In a series of thirty-one of these cases, in which there was no obvious pathological lesion and in which the disparity amounted to 2 mm. or more, the small ventricle was on the smaller side of the skull in ten cases and on the larger side in six. In twelve cases there was no apparent difference between the two halves of the skull. The only deduction to be drawn is that ventricular asymmetry is not uncommon, and when of small degree, is of little diagnostic significance. It is sometimes difficult to decide whether a disparity is pathological or developmental.

Before considering the pathological lesions which may produce asymmetry of the ventricles, it will be necessary to make some reference to lateral displacement and the effect of rotation of the skull upon the skiagraphic appearances. In antero-posterior and postero-anterior films the position of the ventricles is estimated with reference to the sagittal plane of the skull, and not by measurement of the distance from the septum pellucidum to the temporal bones. The visualization of the sagittal plane may be a matter of some difficulty because of the small degree of rotation which is so often present. It is perhaps simplest to determine the middle line of the skull in front (the crista galli is a useful landmark) and behind (using the lambda as an index), and so estimate the position of the sagittal plane in the region being considered. The measurements to the temporal bones may be unequal in cases in which the septum pellucidum is in the sagittal plane. This depends upon asymmetry of the skull and upon rotation, which latter produces very little variation in the ventricular measurements.

Epilepsy

It may be stated that encephalography is most frequently used, and is most useful, in the differential diagnosis of the causes of epilepsy, for by this

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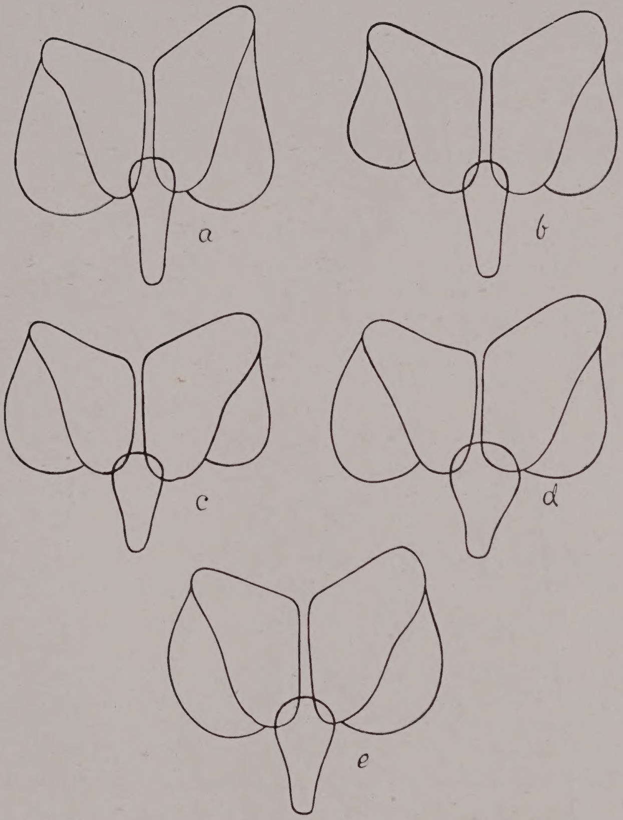

Fig. 55—Antero-posterior skiagrams showing consistent measurements, with a slight increase in the diameter of the ventricles, over a period of two years—(a) encephalogram, July, 1936; (b) ventriculogram, April, 1937; (c) encephalogram, October, 1937, 12 c.cm. of air; (d) same day, 17 c.cm.; (e) encephalogram, November, 1938.

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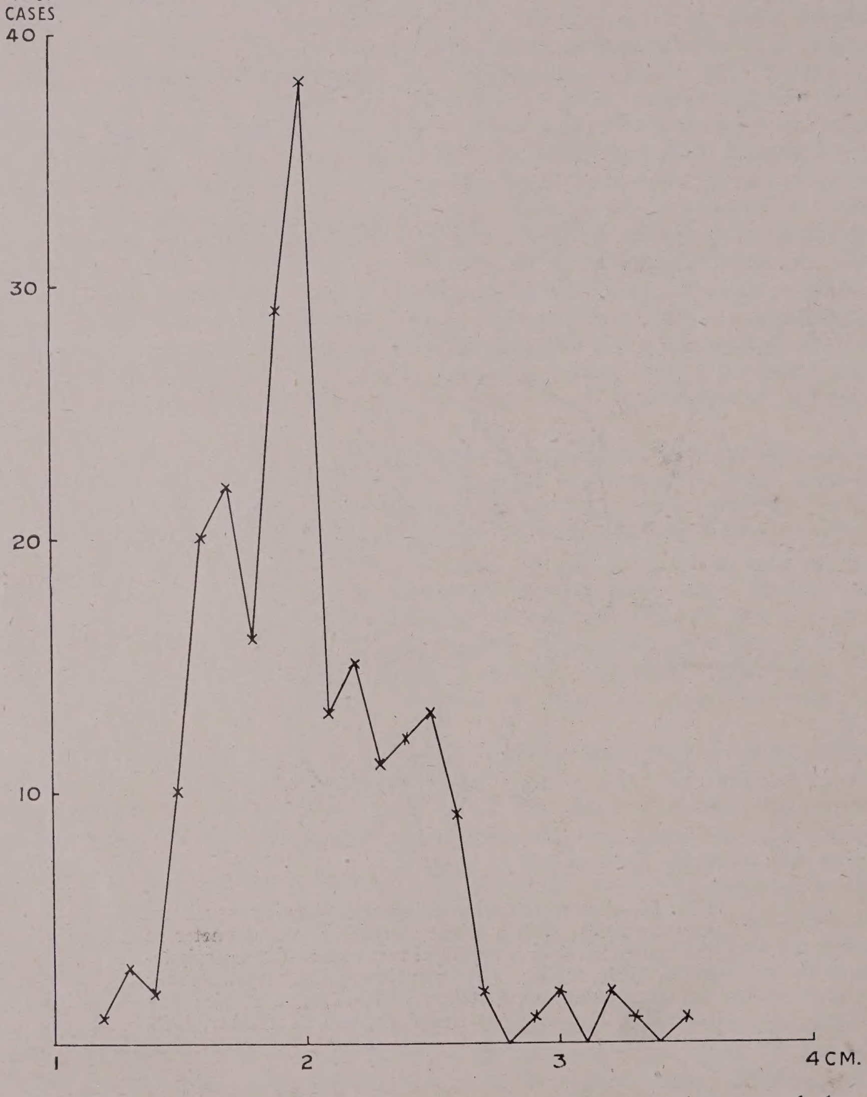

Fig. 56—Graph showing the transverse diameter of the posterior part of the anterior horn in ninety adults.

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means the presence of a neoplasm may be recognized. Yet a great number of practical difficulties arise. The diagnosis of a space-filling lesion is simple if there is encroachment upon a ventricle, particularly if there is also displacement across the mid-line, but the method gives little aid in determining the cause of the epilepsy in those cases in which the ventricles appear normal. The pathological lesion may cause no change in the ventricles or the subarachnoid space. In fact, there may be no demonstrable lesion in cases of focal epilepsy. This has been clearly shown by Furlow (1938) who reported the subpial resection of the area of the cortex electrical stimulation of which led to the patient's typical focal fit. In eight of his sixteen cases, histological examination failed to reveal any abnormality.

If the ventricles appear normal the examiner is prone to assume that no neoplasm is present, but this conclusion may be wrong. It is more correct, in such cases, to say that there is no evidence of a space-filling lesion. In many cases the ventricles are of unequal size, and it may be very difficult to assess the significance of this disparity. In a consecutive series of one hundred encephalographies, performed prior to July, 1939, there were thirty cases of epilepsy without localizing features. In twenty-eight of these, accurate comparative measurements were possible. The lateral ventricles were unequal in twenty (71 per cent.). This group is analysed in greater detail in table III.

TABLE III

Ventricles in Generalized Epilepsy and Petit Mal *

Cause	*Equal*	*Unequal*
Not finally determined †	6	10
Post-traumatic	2	6
Hydrocephalus		1
Syphilis		1
Degeneration		1
Agenesia		1
Total	8	20

* In two of a consecutive series of thirty cases good visualization was not obtained—in one the subarachnoid alone was filled; in the other one ventricle alone.

† A number of these are believed to have degenerative lesions.

In three cases the difference in measurement was 1 mm.; in 5, 2 mm.; in 7, 3 mm.; and in one case each the difference was 4, 5, 6, 12 and 14 mm.

In cases of epilepsy with localizing features the incidence of inequality was much the same, namely 73 per cent. (Table IV).

Of twenty-two cases of focal epilepsy with unequal ventricles suitable for measurement (such conditions as neoplasm, hydrocephalus and gross porencephaly in children were excluded) in five the difference was 1 mm.; in 7, 2 mm.; in 5, 3 mm.; in 1, 4 mm.; 5 mm.; in 2, 6 mm. and in 1, 11 mm. The percentage of inequality in both classes of epileptics was much the same as in a group suffering from headache.

Table V presents the results of a further analysis of the thirty-one cases with inequality of the lateral ventricles in the group of forty-five patients suffering from focal epilepsy.

Five of the group of forty-five cases with focal epilepsy were proven to have cerebral tumours. In four of these the ventricle was smaller on the side of the tumour, whilst in two the ventricular system was displaced away from the tumour. In the fifth, a temporal cyst had been evacuated some time before investigation. The anterior horn was larger on the side of the lesion. In the other thirty-nine cases of focal epilepsy there was no definite evidence of neoplasm. Excluding the five patients with proven tumours, the discharging focus was on the side of the smaller ventricle in eight, of the larger ventricle in fifteen. When the smaller ventricle is on the side of the discharging focus, neoplasm is likely to be suspected; but in the cases here reported the evidence was usually deemed insufficient to warrant exploration. It seems unlikely that a tumour would produce an ipsilateral dilatation at a stage when there is no increase of intracranial pressure and when air enters each ventricle freely. There may, however, have been an intermittent obstruction to the outflow from the ventricle before the investigation was performed, and so a neoplasm may exist on the side of the larger ventricle. Diagnosing the presence and the localization of a neoplasm on the grounds of ventricular inequality alone may lead to serious error. If there is displacement of the ventricular system to the opposite side of the skull, or localized encroachment upon a ventricle, the evidence in favour of neoplasm becomes convincing.

TABLE IV

Ventricles in Focal Epilepsy *

Cause	*Equal*	*Unequal*
Cause undetermined	5	9
Post-traumatic	2	5
Hydrocephalus ? cause	1	1
Aneurysm	1	
Angioma		1
Neoplasm		5
Degeneration		6
Porencephaly		3
Vascular lesion		1
Encephalitis	2	
Total	11	31

* Visualization was not obtained in three of the consecutive series of forty-five cases. In these the pathological causes of the epilepsy were, respectively, aneurysm, cerebral degeneration and undetermined. In the first two the subarachnoid space and cisterns were alone filled. Reference has already been made to the other case, in which failure occurred during the stage of post-lumbar-puncture headache.

TABLE V

Unequal Ventricles in Focal Epilepsy

Ventricle smaller on side of focus in	13
Ventricle larger on side of focus in	17
Uncinate epilepsy without unilateral features	1
Total	31

Difficulties in the diagnosis of neoplasm have been dealt with in an earlier section. All of these cases were examined after the close of this consecutive series, which was limited to allow of an adequate follow-up of the patients. In none of these did subsequent examination suggest the presence of a neoplasm. It is likely, however, that several of the cases really harbour tumours, but this has not been proven. In any large series some cases will undoubtedly arise where increased intracranial pressure eventually draws attention to the presence of a neoplasm, of which an early encephalogram gave no definite evidence. On the other hand, there are a number of cases with unequal ventricles in which there is no evidence of neoplasm, and in which the discharging focus is on the side of the large ventricle. This leads to the consideration of degenerative lesions as a cause of epilepsy.

Degenerative, atrophic and aplastic lesions

Although it is probable that many cases of focal and generalized epilepsy in middle and later life harbour occult neoplasm, it is believed that degenerative lesions are responsible for a large percentage of cases. Additional evidence of atrophy would have been obtained if the cerebral sulci were filled in each patient, but in the early investigations this was not done. It was thought that the patient would gain little to compensate him for the additional discomfort of the complete investigation. From a statistical point of view, however, this is unfortunate.

Grant (1932) studied seventy-two cases of epilepsy by encephalography, apparently excluding cases due to neoplasm. He found normal encephalograms in sixteen cases. The ventricles were asymmetrical in only four patients. Atrophy was the principal finding in forty, arachnoiditis in sixteen. In the atrophic group one or both ventricles were dilated in sixteen cases, normal in twenty-four; where arachnoiditis was present the ventricles were dilated in eleven, normal in five. Of fifty-one post-traumatic cases the encephalograms were normal in five. Ventricular asymmetry was found in twenty-three. Atrophy was the principal finding in twenty-eight (one or both ventricles were dilated in twenty, compared with normal ventricles in eight), arachnoiditis in eighteen. Arachnoiditis has not been a common finding in the present series, the subarachnoid space being studied in only a limited number of cases.

Typical cases

The importance of degenerative lesions as a cause of epilepsy justifies the description of two typical, yet different, cases.

M.M.J., a police inspector of fifty-seven years stated that during twelve years he had noticed a tingling, numb feeling in the tips of the fingers of the left hand. These gradually spread up the arm in later attacks which lasted a few seconds and recurred at long intervals. At the end of two years the numbness reached the face round the right eye, and then extended downwards over the right side of the face "causing twitching of the right side of the mouth" for a few seconds. At the time he felt a constriction in the throat which made him inarticulate for a few seconds. Shortly before investigation an attack occurred in which, following upon the usual march of dysaesthesiae, the right side of his face commenced to twitch and continued to do so for four and a half hours, the left side twitching synchronously but less violently. After the attack he could formulate sentences in his mind but could not articulate or write. He eventually fell asleep and the next morning only slight slurring of speech remained.

On examination three days later, there was slight weakness of the right side of the face and the abdominal reflexes were diminished on the right side. Ability to distinguish between single and double contacts fatigued rapidly in the right hand. The blood pressure was normal. The cerebrospinal fluid was normal and the initial pressure was 140 mm. The Wassermann reaction was negative in blood and cerebrospinal fluid.

Encephalography revealed considerable dilatation of the body of the left lateral ventricle, particularly in its posterior part (Fig. 57). The sulci on this side were slightly widened. In the two years following investigation, during which he was treated with bromide and phenobarbital, the patient has had a few attacks of short duration, the spread of which he was sometimes able to stop by the application of a tight band around his wrist. The last two attacks commenced in the neck, prevented articulation, and then extended into the right side of the face causing the usual twitching. The attack then appeared to fade out. Within a short time the numbness and pins and needles recommenced in the fingers of the right arm and travelled up to the elbow. The ventricular dilatation may have been recent onset or of congenital or natal origin.

F.H., a man of forty-five years stated that eighteen months before investigation he suddenly felt "as if something were attacking his left side." The impression was so strong that he sidled away from this "something," and described three complete circles. On closer analysis he stated that something which seemed to be hot and blunt started in his left lower abdomen and worked upwards to his face. He felt that his nerves were working and jerking on the left side, and the attack "made him draw his left arm upwards." Three months later, he commenced to have attacks of varying severity in which he lost consciousness; in one twitching of the left arm and leg was noted. The attacks became more frequent over the following fifteen months, until he was having several each day. While falling asleep he frequently experiencd a hot feeling in the region of the left knee, which seemed to make the leg kick for two or three minutes. The feeling worked up his left thigh and the left side of the trunk. Occasionally he felt something which he described as a flow of blood in the left side of his body.

The pupils were small and reacted feebly to light, though better to accommodation. The deep reflexes were feeble and the left abdominal reflexes were reduced. Skiagrams of the skull were normal. The pressure of the cerebrospinal fluid was 120 mm. and the fluid was normal. The Wassermann reaction was negative in the blood and cerebrospinal fluid.

Although to some extent a recapitulation, the complete investigation of this case will be described. The filling was observed in lateral views taken after the introduction of successive quantities of 6 c.cm. of air (Fig. 58). The cisterna magna, the fourth ventricle, the aqueduct of Sylvius, the posterior part of the third ventricle and one occipital horn were faintly outlined after the first introduction, which occupied five minutes. After 12 c.cm. had been introduced, the shadows of the median passages were denser, and there was an increase in the amount of air in the posterior parts of the lateral ventricles (Fig. 58a). The shadow of the cisterna magna did not increase in density after the first introduction. The antero-posterior diameter of the fourth ventricle was rather greater than usual. A postero-anterior skiagram, taken with the head erect and the patient's nose and forehead against the film, revealed no abnormality. An antero-posterior film, taken in recumbency, revealed general enlargement of the lateral ventricles, the right being smaller than the left (2·2 : 2·5 cm.). The third ventricle was 5 mm. in width (Fig. 58b). The inter-axial view confirmed the central position of the ventricles and the absence of any displacement of the septum pellucidum (Fig. 58c). A postero-anterior film showed large trigones and temporal horns (Fig. 58d) and the choroid plexuses were large. Lateral views confirmed the general dilatation of the ventricles (Fig. 58e). Antero-posterior films taken with the head in each lateral position afforded views of each temporal horn (Fig. 58f). The patient was then posed to transfer some of the air to the subarachnoid space over the cerebral hemisphere. A number of irregularly-rounded dilatations of the subarachnoid space could be seen over both hemispheres (Fig. 58g). Apparently the patient was suffering from a form of general cerebral atrophy, probably of recent origin.

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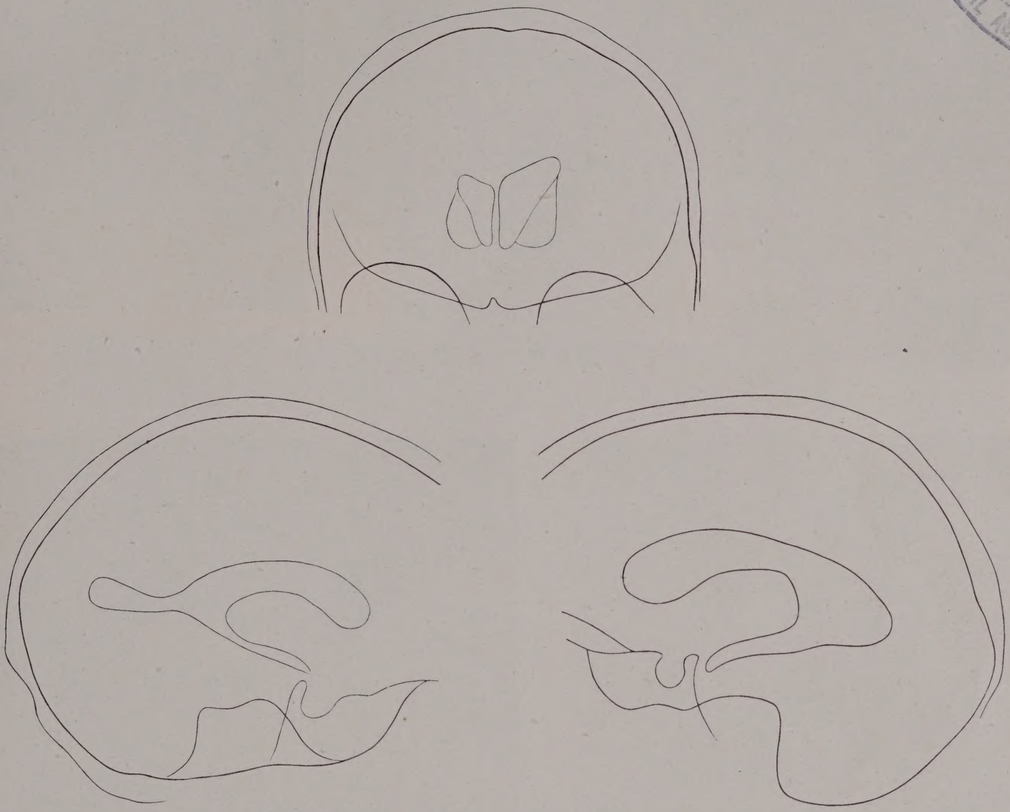

Fig 57—Enlargement of a lateral ventricle, apparently due to atrophy or aplasia—
(a) antero-posterior skiagram;
(b) right lateral ventricle;
(c) left lateral ventricle.

To face page 82.

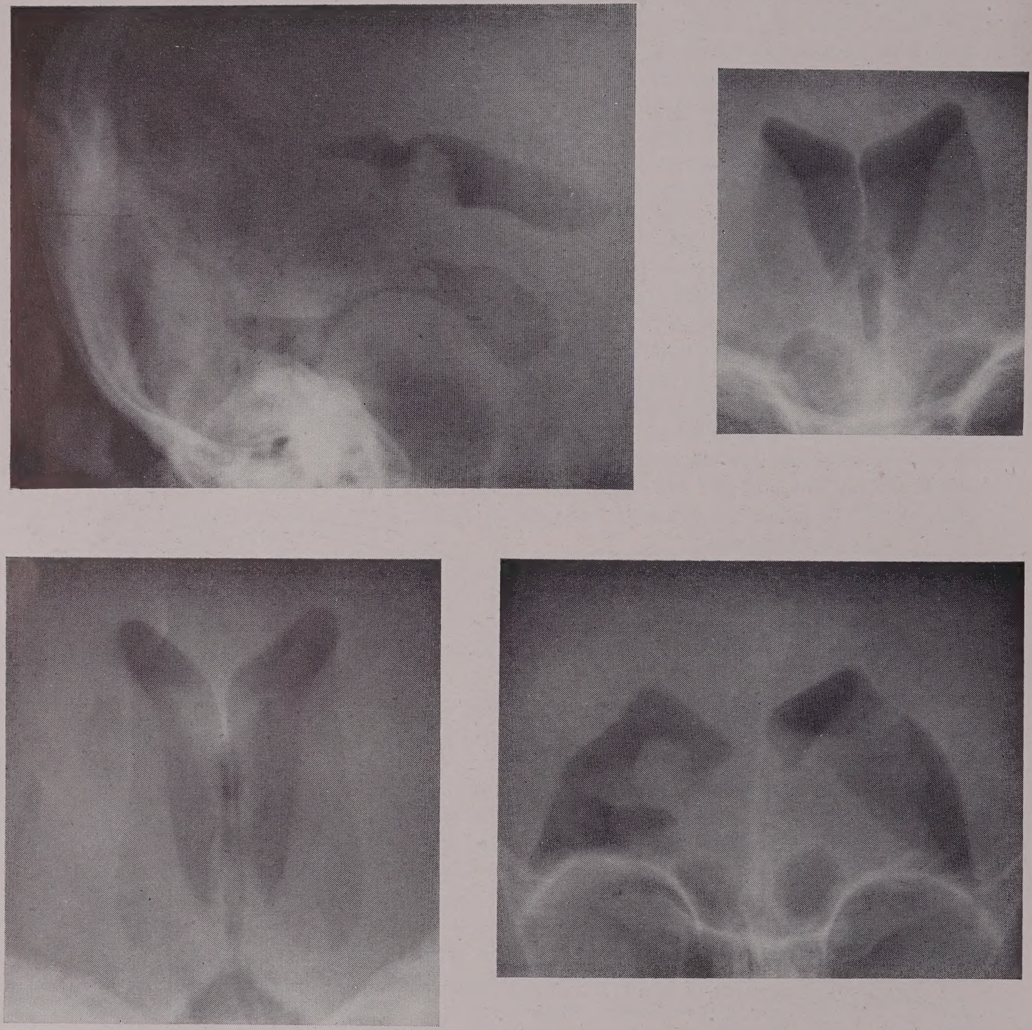

Fig. 58—General cerebral atrophy—(a) lateral view, with head flexed, 12 c.cm. of air; (b) antero-posterior film, brow up, 24 c.cm. of air; (c) inter-axial film; (d) postero-anterior film; (e) one of the lateral ventricles; (f) antero-posterior film, with head in lateral position, to show the temporal horn; (g) lateral film after transfer of some of the ventricular air to the subarachnoid space.

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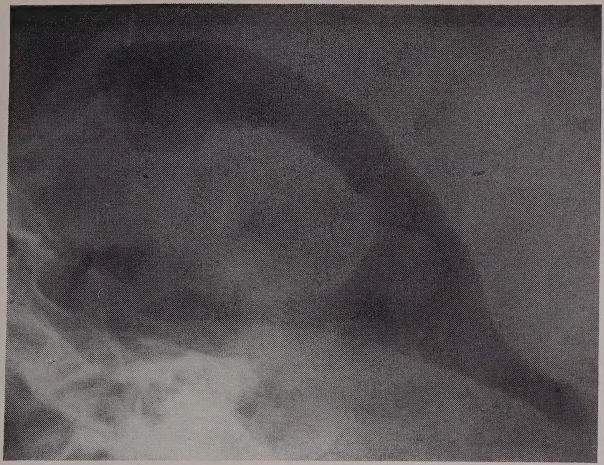

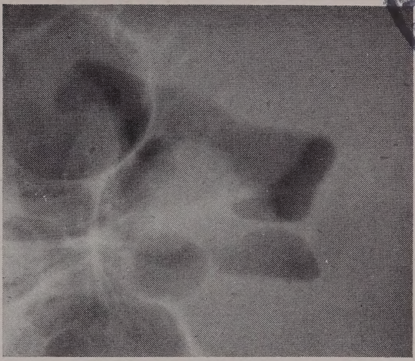

In some cases the interpretation of the encephalographic findings is difficult. The next case is described because it represents a fairly common type, and the picture is likely to prove confusing.

L.A., an intelligent man of thirty was involved in a motoring accident seven years before examination and was unconscious for half an hour. Subsequently he was able to walk home and did not remain in bed. Two years later he fell and remained unconscious for fifteen minutes. On recovering he felt a violent vertical headache. He had five similar attacks during the next three years, and during part of this time he suffered from severe continuous headache running through the head between the temples. Six years after the onset he one day commenced to spin round from left to right, his face rigid, foaming at the mouth. There was a little twitching of the hands. After this attack he suffered from headache for a few days. A year later continuous headache commenced, like a band across the forehead, sometimes felt more severely in the right anterior parietal region as a beating, thumping pain. After three months he noticed a sharp, localized pain in the right anterior parietal region whenever he coughed or sneezed. At about this time he experienced an attack in which there flashed through his mind conversations with people whom he had known years ago, in places he had known years ago—"a merry-go-round of vivid, jumbled scenes, with a feeling of familiarity." A companion stated that he walked about in an aimless fashion for some minutes, taking no notice of his surroundings. Then after spinning round he fell unconscious. On recovery of consciousness there was localized headache which remained until the time of examination two days later.

There were no abnormal physical findings. Skiagrams of the skull revealed no abnormality and the cerebrospinal fluid was normal. The right lateral ventricle was considerably smaller than the left (1·6 : 2·1 cm.) ; the third ventricle and the septum pellucidum were situated slightly to the right of the mid-line and the sulci over the right hemisphere were slightly widened. It appeared possible that there was under-development of the right cerebral hemisphere. The part played by the trauma seven years before was difficult to evaluate. Although related in time of onset to the epileptic attacks, the localized headache appeared to be of post-traumatic type. Similar findings were encountered in a patient who, at the age of seven years, commenced to suffer from major and minor epilepsy. In the major attacks, before losing consciousness, he experienced a peculiar feeling in the right great toe which rapidly spread over the right side of the body. His birth had been slow, and during instrumental delivery a dent was caused on top of the head. Examination of skiagrams showed that the left side of the skull was slightly flattened and was less capacious than the right. The left ventricle was smaller than the right (1·7 : 2 cm.) and the septum pellucidum was 4 mm. to the left side of the mid-line. The left hemisphere, including the ventricle, appeared to be smaller than the right. Apparently a small ventricle may result from injury to the corresponding hemisphere during birth, although enlargement is the more usual finding.

Causes in early life

An atrophic cerebral hemisphere or a localized area of atrophy may follow a head injury, sustained at birth or at any later period. The effect is more likely to be profound in early life for the development of the brain may be retarded. The view is frequently to be found in the literature that damage at birth is of small consequence because of the more primitive nature, and therefore greater adaptability, of the cells and structures involved. The contrary view—that these primitive cells, being the predecessors of all that can follow, have a quite special importance—is more in keeping with the observed results of early damage. The outcome of obstetrical procedures is not limited to the mere death or survival of the new-born babe. Prolonged ischaemia, due to anoxaemia during the birth period, has been suggested as a frequent cause of localized atrophy. It is difficult to conceive that a condition of anoxaemia affecting the entire skull contents should lead to the destruction of isolated areas of tissue—glia and neurones alike. Conditions acting generally and sufficiently severe to produce such massive death of tissue, would hardly leave the vital centres capable of function.

It is probable that trauma producing haemorrhage or contusion is the most frequent cause of so-called idiopathic epilepsy. Porencephaly illustrates the severest grade of such a process. A minor degree of a similar type of lesion may produce little alteration in the ventricles and yet act as a focus for epilepsy, which is likely to occur in early life, but might conceivably commence at any age. Intermediate stages occur frequently. Under-development of one cerebral hemisphere without any off-setting increase in fluid will lead to under-development of the cranial vault on that side, and the septum pellucidum may be displaced towards the affected side. Dyke, Davidoff and Masson (1933) described nine cases suffering from convulsions and hemiplegia commencing early in life. Skiagrams revealed thickening of the cranial vault on the side of the affected cerebral hemisphere, with over-development of the frontal and ethmoidal sinuses and of the air cells of the petrous temporal bone on the same side. In encephalograms the corresponding lateral ventricle was seen to be enlarged and the third ventricle was sometimes displaced towards the side of the lesion. Casamajor and Laidlaw (1939) describe and illustrate nine such cases. They divide the causes into traumatic, vascular and inflammatory. Robertson and Childe (1940) have made accurate estimations of the position of the ventricular mid-line and show that it may be displaced towards the side of an atrophic lesion in the absence of meningeal adhesions.

When the bulk of cerebral tissue is reduced the encephalographic appearance will depend upon the size of the skull, or upon the distribution of compensatory collections of fluid. The ventricles and the sulci may be widened. In some conditions, in which the degeneration is for the most part neuronic, the encephalogram may be normal. In others, glial proliferation may reduce the size of the ventricles. A girl of sixteen suffering from a spastic paraparesis was found to have small lateral ventricles (right 1·3 cm. : left 1·2 cm.), separated by a wide septum pellucidum. Subsequently it was found that two brothers had a similar clinical condition, all having walked normally in their early years. This suggested the diagnosis of familial spastic paralysis.

Often, as in the following case, the findings are difficult of interpretation.

L.M., a man of thirty-one gave the following history. He was the fourth of a family of eight, the remaining seven being healthy. There was no medical assistance at the confinement, and labour lasted twenty hours. The patient appeared to be normal at and after birth. He sat up at eight months. When twelve months old he was found crying in a runaway perambulator, the swift downhill course of which had been interrupted by a tree. Later, it was thought that he might have sustained a head injury. When, at twenty months, he commenced to walk, weakness of the left leg and "floppiness" of the left arm were noticed. A week after he had taken his first steps he commenced to suffer from paroxysms in which he lost consciousness, and convulsive movements spread from the left arm to the left leg and the left side of the face. For two months he made no further attempts at walking. His intelligence appeared to be normal, although he was not quite as advanced as his brothers. The

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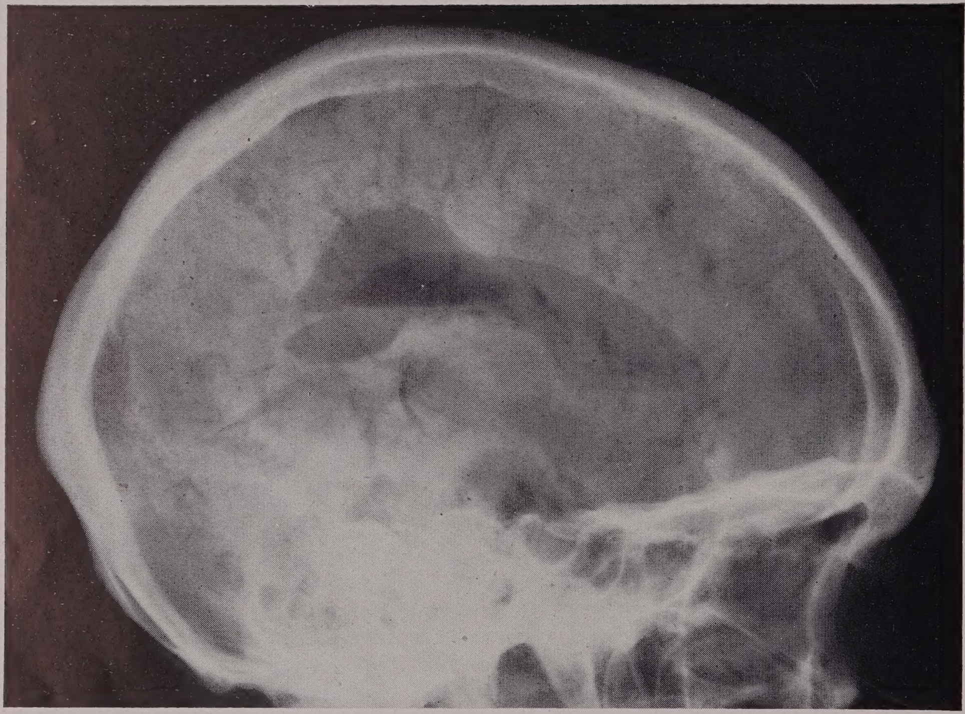

Fig. 59—Lateral skiagram with head erect showing a diverticulum of the right lateral ventricle, which was beneath a venous angioma.

paroxysms recurred with great frequency. The weakness of the left arm and leg was gradually progressive, though it was worse after each long succession of fits. In his early years no warning preceded the loss of consciousness; but after the age of fourteen years a sensation of numbness used to appear "over the heart" and rapidly spread up the left side of the face and head; the left arm became elevated and flexed at the elbow. his head then seemed to spin round, the numb feeling pervaded his body, his knees gave way under him and he lost consciousness. His mother stated that the left arm began to twitch at this stage, and the convulsion spread to his mouth and the left lower limb. After recovering consciousness he usually felt severe headache over the right parietal region. There was a left-sided hemiparesis of upper motor neurone type, with contracture and hemiatrophy. Discriminative sensibility was slightly impaired on the left side. There was a moderate degree of reduction of the higher cerebral faculties. Skiagrams revealed pronounced asymmetry of the skull, the right side being less capacious than the left. The cerebral ventricles were outlined by 20 c.cm. of air introduced by the lumbar route. Films showed a localized diverticulum extending upwards and outwards from the posterior half of the body of the right lateral ventricle (Fig. 59). The whole ventricular system was displaced towards the right. Air in the subarachnoid space extended over the left cerebral hemisphere, but not over the right parietal lobe. The cerebrospinal fluid was normal.

It appeared most likely that the lesion was a "traction diverticulum" of traumatic origin. It was obvious, however, that the cortical abnormality was of greater extent than the area over the diverticulum; for the right side of the skull was smaller than the left, the ventricles were displaced to the right, and hemiplegic signs indicated involvement of the precentral gyrus. Yet, as the diverticulum corresponded to the focus of the attacks, it seemed reasonable to attempt to cure the epilepsy by excision of the overlying cortex.

This area of the brain was therefore explored. A plexus of veins embedded in thickened pia-arachnoid overlay the posterior parietal cortex, reaching to within 4 cm. of the sagittal sinus. Exploration with a needle proved that this area corresponded to the apex of the ventricular diverticulum, which lay about 1 cm. below the surface. By means of silk ligatures and silver clips the vessels running to this plexus were occluded and divided. The area of cortex superficial to the ventricular diverticulum, measuring 4 cm. by 3 cm. was then removed, with the aid of a diathermy knife, opening the ventricle widely. Evidence of abnormality of the surrounding brain was seen in the widened sulci containing pools of fluid. Since the operation the epilepsy has been much less frequent. In the last two years he has had only twelve small attacks, without loss of consciousness.

It was expected that the excised tissue, on microscopic examination, would reveal scar tissue, but this was not the case. Overlaying the brain a number of large thin-walled veins were seen to be embedded in cellular fibrous tissue. There were also a few smaller vessels with thicker muscular walls containing an internal elastic lamina. The cortex contained no large vessels, but rather more capillaries than usual. It was packed with an abnormal number of neurones, completely lacking the usual architectural arrangement. The cells, though small, appeared to be healthy, and the Nissl granules were normal in the few larger cells present. The loss of substance appeared to be at the expense of the white matter rather than the grey. The myelin stained normally. Stains for neuroglia revealed only a slight increase in the cells and fibres. The microscopic structure therefore suggested that this was not a scar secondary to cerebral contusion. Two other explanations are possible. An atrophic process of the right cerebral hemisphere, initiated at an early age and most intense in a small area, is a possible explanation. Certainly the cortical veins are often found to be large near areas of cortical atrophy, but the cortical cells over the diverticulum do not suggest atrophy, but rather a process of condensation. The neurological signs are, however, proof of malfunction, and indicate an atrophy, at least, of other areas of the cerebral hemisphere. It is probable that there is a widespread developmental anomaly, accounting for atrophy and dysfunction of a large area of the cerebral hemisphere, and an abnormality of development of the blood vessels—a venous angioma.

Causes taking effect in adult life

In a discussion of presenile dementias Critchley (1938) sets out what he terms "a working classification based on a clinico-aetiological foundation":

- The syphilitic dementias
- Arteriosclerotic dementias
- Traumatic dementias (including the sequelae of cerebral laceration, chronic subdural haematoma, etc.)
- Cerebral tumour (and abscess)
- Epileptic dementias
- Secondary dementias (supervening upon psychoses)
- Dementia complicating chronic neurological disorders (disseminated sclerosis, epidemic encephalitis, subacute combined degeneration of the cord, Huntington's chorea)
- Dementia associated with chronic toxi-infective states (uraemia, lead, alcohol, hashish, barbiturates, pellagra)
- Specific dementias of unknown origin (Pick's disease, Alzheimer's disease)

Pendergrass (1930) in relation to encephalographic studies stated that "some form of atrophy of the brain has been present in all cases of the convulsive states that I have studied." He presents an unusual explanation of the causation of such atrophic processes and quotes from a report of a Committee on Standardization of Encephalography, appointed by the President of the American Roentgen Ray Society:

> It was accepted by the Committee that the generalized shrinkage and atrophy in the frontal and parietal areas is a pressure atrophy of the ischaemic type . . . the pressure mechanism consists of a delay in the escape of cerebrospinal fluid from the channels over the fronto-parietal area, thereby permitting excessive accumulations of fluid in the subarachnoid space. The factors underlying these disturbances are probably those which impair or destroy the function of the pacchionian bodies or subarachnoid villi, such as free haemorrhage in the subarachnoid space, trauma following birth injury, inflammatory or toxic processes, and infiltrative processes, such as metastatic carcinoma.
>
> . . . Changes of pressure are produced by over-production of fluid compared to its escape, by coughing, straining, crying and other exertions. They temporarily, or more or less permanently cut down the capillary vascular supply, and with a fixed fluid "cast," favour pressure atrophy through ischaemia, or favour lack of normal development.

In two cases in this series the ventricles and the subarachnoid space over the lower part of the hemispheres were dilated, but the subarachnoid space was obliterated above, presumably by arachnoiditis. In one patient this was produced by syphilis, which also afforded a sufficient explanation of the cortical atrophy; in the other (depicted in figure 66) there was no obvious cause, although there had been chronic otorrhoea before the slow onset of the cerebral symptoms. Blockage of absorption of cerebrospinal fluid is certainly an important factor in some cases, but it is believed that the atrophy follows other causes in a greater proportion of cases than the mechanical theory suggests.

Vascular causes

An impoverished blood supply may produce a progressive generalized degeneration, or a localized atrophy. Greenfield has summarized recent knowledge of vascular causes of presenile dementia under the following headings:

> Cases with evident softening and haemorrhage associated with patchy or diffuse arteriosclerosis.
>
> Verrucose or granular atrophy of the cortex, usually associated with degenerative change in the cortex of the kidney and hyperpiesis. The degeneration affects both nerve-cells and fibres in an irregular manner and is associated with an overgrowth of neuroglial fibres. It appears to depend on sclerosis of the small cortical arterioles.
>
> "Areas of paling" of the cortex due to focal degeneration of nerve cells. There are no naked-eye changes in the vessels or in the texture of the brain. The patient has usually had a high blood pressure during life and on microscopic examination intimal proliferation is seen in the small cortical vessels.

It may be stated that vascular diseases are common causes of cerebral atrophy. Thrombosis in veins and venous sinuses may be responsible for subsequent atrophy. A lesion due to obstruction of the larger arteries follows the pattern of arterial distribution and hence may be readily recognized. It is believed, however, that there are localized vascular lesions which are not readily recognized as such. Indeed, even when the pathological picture has been closely studied it may be difficult to recognize the underlying pathological change. In one patient detailed observation was possible from the time of onset of acute symptoms to his death, when pathological examination was carried out.

H.G., was a placid man of poor intellectual development, but over a period of fifteen months he had become irritable, excitable, antisocial and untidy. Six months before admission to hospital he commenced to suffer from headaches at the back of the head and neck. Eight days before admission he returned home, carrying his cycle on his shoulder, and said that he had had a fall. During the next day he complained of frontal headache and defective vision. After this, he was unable to read a newspaper, and seven days later he was troubled by a bad smell, and made his wife search for a possible source. His appearance and manner were peculiar for some fifteen minutes; then he lost consciousness for a few minutes, and both sides of his body commenced to jerk. Twenty minutes later he had another similar fit in which he bit his tongue. A third attack followed on the day of his admission to hospital.

Accurate examination was impossible because of his confused mental condition. The deep reflexes were more active on the left side than on the right, and the left plantar response was extensor. The blood pressure was not elevated and the urine was normal. The cerebrospinal fluid was under a pressure of 150 mm. It was clear and colourless, but formed a pellicle. There were 350 lymphocytes and 25 large mononuclear cells per c.mm. The protein content was 40 m.gm. per cent. and the chlorides 740 m.gm. per cent. The globulin was slightly increased. Lange's colloidal gold test was normal, and the Wassermann reaction was negative in both blood and cerebrospinal fluid. The temperature varied between 101·5 and 103° for three days. He was drowsy and at times stuporose, but if roused was irritable and abusive. He gradually became less drowsy, and at the end of six weeks his behaviour resembled that of a docile but stupid child. The number of cells in the cerebrospinal fluid gradually decreased until four months later there were fifteen lymphocytes and one large mononuclear per c.mm.; but the colloidal gold reaction gave a curve of markedly paretic type—4555555444. The total protein was 70 mg. per cent. and the globulin was increased. Chlorides and glucose were normal. The colloidal gold curve was consistently abnormal and the Wassermann reaction always negative. Three months after admission encephalography showed dilatation of the left temporal horn (Fig. 60a, b) the ventricles being otherwise normal. As the weeks passed, periods of exaltation supervened, with irrational garrulousness of limited vocabulary and, at times, great motor activity. Speech became confused and he would repeat meaningless phrases for long periods. He was emotionally unstable, at times weeping, at times singing snatches of tuneless song. There were fragmentary delusions of persecution, and visual and auditory hallucinations. Motor activity became uncontrollable, and eventually, in an exhausted state, he died of pneumonia.

The brain showed extreme shrinkage of the left temporal lobe, especially in its anterior part (Fig. 60c). Large veins were seen running upwards over both hemispheres and converging upon the longitudinal sinus. The left Sylvian veins were large, but were not thrombosed. Microscopically they appeared normal. The meninges of the basal cisterns were thickened. The middle cerebral artery and its larger branches were patent. Coronal sections (Fig. 60d) showed that the anatomical distinction between grey and white matter had been lost in the left temporal lobe. The degeneration was most extreme near the temporal pole. More posteriorly it mostly affected the superficial parts, which were replaced by yellow material containing many cavities. This process was confined to the temporal lobe on the left side, and on the right side was commencing in the region of the hippocampus.

On microscopic examination the meninges were seen to be thickened, with lymphocytic infiltration and proliferation of fibroblasts. The arteries in the meninges showed thickening and sclerosis, particularly of the media, while some vessels showed medial degeneration and calcification in the adventitia. The pathological process appeared to begin in the deep layers of the cortex (Fig. 60e). The commencing process was best seen in the region of the right hippocampus (Fig. 60f). Cellular infiltration was prominent, and was perivascular, focal and diffuse in distribution. The focal areas were most evident in the nerve-cell layers. Most of the cells were lymphocytes, but there was a fair proportion of microglial cells and occasional plasma cells. The vessels were engorged; some running deeply into the white matter showed perivascular infiltration.

In the left temporal lobe there were large areas of necrosis of tissue, most marked near the surface. In places this had led to the formation of cavities lined by necrotic material. The temporal pole appeared to be necrotic. More posteriorly, the superficial layers of the cortex were much less affected. Beneath this zone there was a band of degenerated necrotic material filled with fat-laden microglial cells and lymphocytes (Fig. 60e). This appeared to involve the deeper layers of the cortex and the superficial part of the white matter. Beneath this zone were fibres stained by the Weigert-Pal method, mingled with fat-laden microglial cells. In other places, particularly near the temporal pole, there were areas of massive necrosis in which the pale outlines of the infiltrating cells, now dead, could be seen. The necrosis had involved the astrocytes as well as other cellular elements. In no part was there any great proliferation of astrocytes. The vessels of the circle of Willis appeared normal. One of the main branches of the middle cerebral artery showed patches of splitting and multiplication of the internal elastic lamina and the intima was thickened. About a third of the lumen of one of the temporal branches was obliterated by closely packed fibroblasts and fibrous tissue. This appeared to represent an organizing thrombus. The internal elastic lamina, media and adventitia were normal. Some of the small arteries within the degenerative area showed intimal proliferation but the majority were unaffected. There was no post-mortem evidence of cardiovascular or renal abnormality.

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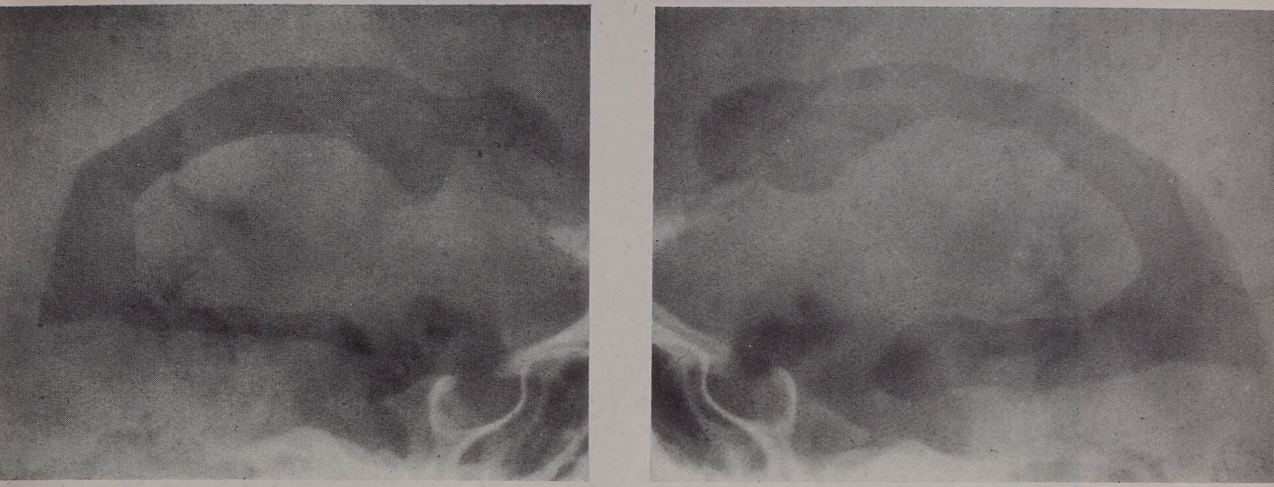

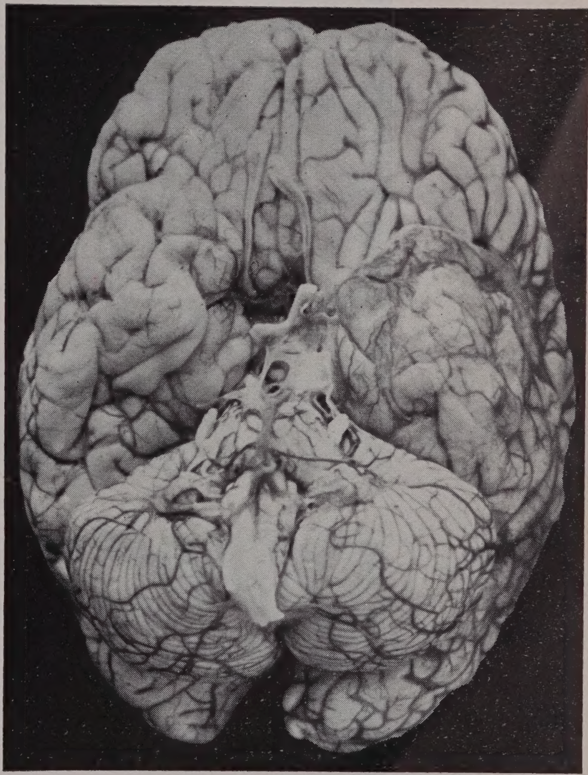

Fig. 60, a, c—Localized atrophy—(a) right lateral ventricle; (b) left lateral ventricle, showing dilatation of the temporal horn; (c) atrophy of the left temporal lobe. (See Fig. 60d, e, f, overleaf.)

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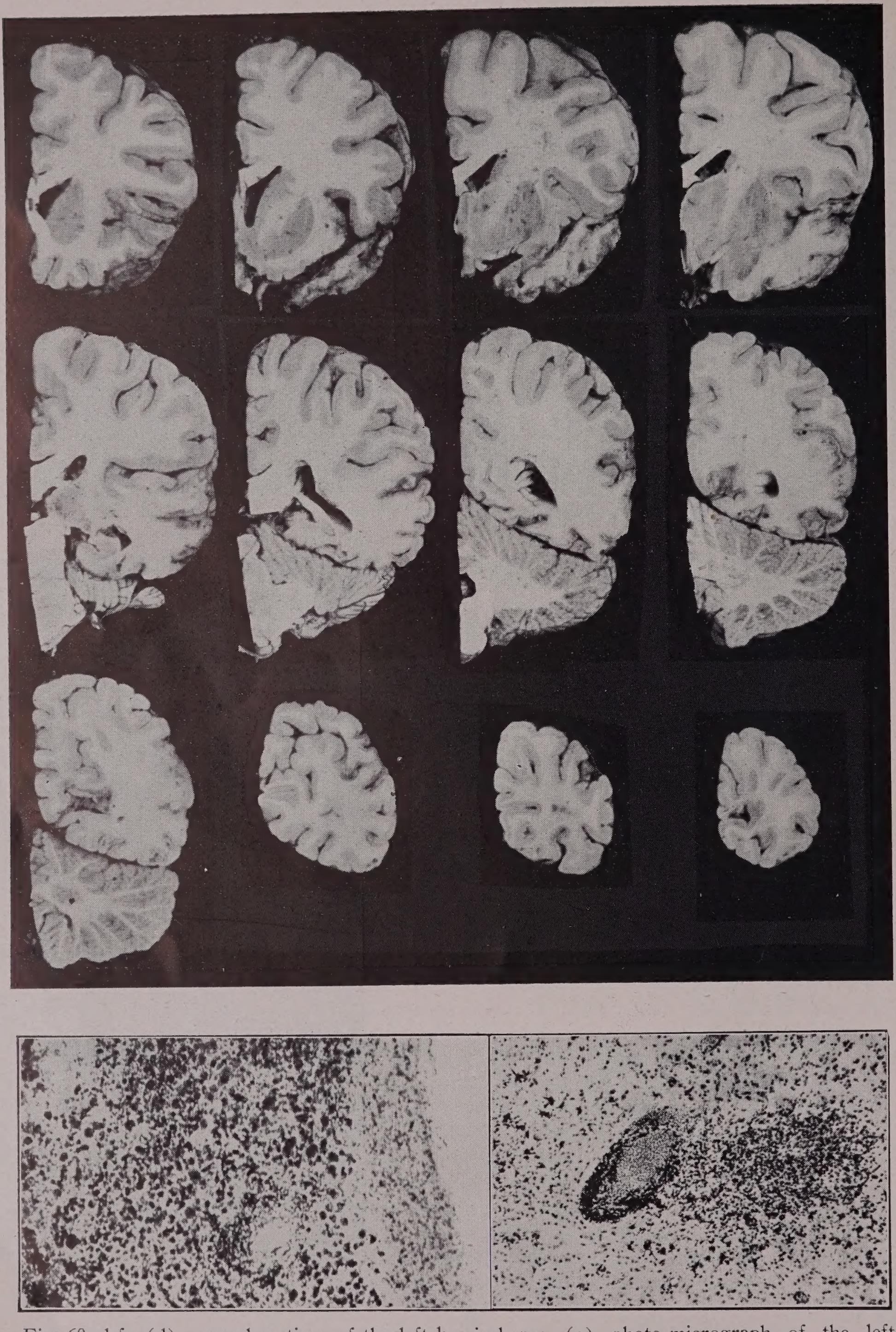

Fig. 60, d-f—(d) coronal sections of the left hemisphere; (e) photo-micrograph of the left temporal cortex; (f) photo-micrograph of the right hippocampus.

To face page 89.

The cause of the lesion is obscure. The dilated cortical veins showed no evidence of disease; similar dilatation has been seen at operation in cases of cerebral degeneration. The atheroma of the branches of the middle cerebral artery and the organized thrombus may have an aetiological significance, but these may possibly have been secondary to an inflammatory or degenerative lesion. The meningeal thickening and intense perivascular infiltration perhaps suggest an inflammatory condition, but it is difficult to state whether the lesion was degenerative, vascular or inflammatory.

At a later date a second case was encountered which, in some of its features, resembled the first. An unusual type of vascular lesion was clearly the cause. The case provides another example of the difficulty of interpretation of the ventricular picture, for the anterior horn and body of the ventricle were smaller on the side of a degenerative lesion.

A.Z., a man of thirty-nine suddenly found, six weeks before admission to hospital, that he was unable to answer questions and could only speak a few disjointed words. At the same time he experienced headache over the left eye. By the next day he had recovered. Three weeks later he was again unable to speak, although he understood everything that was said to him. There was also slight weakness of the right arm. In spite of these attacks he was able to continue at work, but after the second, he noticed a variable difficulty in verbal expression.

Examination revealed an almost complete right-sided homonymous hemianopia and slight weakness of the right side of the face and the right arm. The reflexes were normal. Stereognosis were not as accurate in the right hand as in the left. There appeared to be considerable reduction of his higher cerebral faculties. The cardio-vascular system was normal on examination. The blood pressure was 140/80. The pressure of the cerebrospinal fluid was 140 mm. It contained 10 lymphocytes per c.mm. The protein was 55 m.gm. per cent. and the globulin was not increased. The colloidal gold curve was normal and the Wassermann reaction in blood and cerebrospinal fluid was normal. In plain skiagrams the left side of the skull was seen to be less capacious than the right. Twelve days after admission he had a series of four fits. Two were generalized, but two commenced in the left hand before involving other parts of the body. Seven days later the cerebrospinal fluid contained 19 lymphocytes and 4 large mononuclears per c.mm.

A week later encephalography showed that the right lateral ventricle was larger than the left (2·7 : 2·0 cm.). This is shown in figure 61a. The septum pellucidum lay 8 mm. to the left of the mid-line. The posterior parts of the ventricles were more symmetrically disposed. The left temporal horn was larger than the right (the vertical diameters in lateral views were—9 : 6 mm.). In antero-posterior views, however, the left temporal horn, appeared narrower from side to side than the right. The body of the left temporal horn was situated 5 mm. nearer the temporal bone than that on the right side. The tip of the left temporal horn curved downwards, while the right was straight. The third ventricle was normal. The sulci on the medial surface of the hemispheres and in the region of the left Sylvian point appeared to be wider than usual. The conjunction of a small anterior horn and body on the left side, with a flattened parietal bone on that side and displacement of the septum pellucidum to the left of the mid-line, suggested the presence of a poorly-developed left hemisphere. It was not realized that this condition concealed the evidence of an atrophic lesion, although clues were provided by the enlarged left temporal horn and the dilated sulci.

There was some transient improvement, but a month later, during the afternoon, he collapsed. On recovering consciousness there was marked weakness of the right side and he could only say "Yes" and "No." During the night he could not be roused, and in the morning the hemiplegia was complete. Later he became noisy and restless. The cerebrospinal fluid was blood-stained and under a pressure of 350 mm. The temperature rose to 101° F. A week later the pressure of the cerebrospinal fluid was still high and the fluid contained 3 lymphocytes, 1 large mononuclear and 26 erythrocytes per c.mm. and 250 m.gm. of protein per cent. Subsequently the speech became clearer and the mental state brighter. The temperature was intermittently high, probably because of an infection of the urinary tract. Five weeks later the right leg was swollen and red and hot, with a moderate accumulation of fluid in the knee-joint. The axillary temperature was 1·5° F. higher on the right side than on the left. This state of affairs subsided after four days. The aphasia and hemiplegia were complete and rigors were frequent. Blood cultures were negative. Twelve days later (six months after the onset of illness) he had a series of fits and he died two days later.

Post-mortem examination revealed broncho-pneumonia and cysto-pyelonephritis. The renal lesion appeared to be recent. There was no evidence of abnormality of heart and blood vessels. Unfortunately the systemic blood vessels were not examined microscopically. The left cerebral hemisphere appeared to be smaller than the right. The pia-arachnoid over the left parieto-temporal region was thickened and showed yellowish pigmentation. The anterior horn and body of the left ventricle were smaller, and the trigone and temporal horn were larger than the corresponding parts on the right side. An area of degeneration was evident just lateral to the tip of the anterior horn (Fig. 61b). More posteriorly, the degeneration affected a wider area, involving the upper part of the corpus striatum, the head of the caudate nucleus and the thalamus, and spread out in a wedge-shaped area to the cortex of the lower part of the frontal and parietal lobes. In its most posterior part the degeneration spread from the superolateral angle of the trigone to the surface. The central areas showed massive necrosis. At the periphery and in the overlying meninges there was an accumulation of fat-laded microglial cells, which were most numerous around the blood vessels. Where these cells were less dense fibroblasts, plasma cells, lymphocytes and polymorphs were seen. There was relatively little lymphocytic infiltration of the perivascular spaces.

The vessels composing the circle of Willis were normal microscopically. Some of those in the stem of the left fissure of Sylvius showed occasional small patches of atheroma with fragmentation of the internal elastic lamina. The larger arteries in the degenerated area showed marked changes. A part of the lumen of one was occupied by an organizing thrombus—tissue containing fibroblasts and some erythrocytes with a small quantity of blood pigment on the free surface (Fig. 61c). A thin layer of similar tissue lined the remainder of the lumen. The internal elastic lamina was intact. The lumen of another artery was occupied by a plug of tissue in which recanalization by endothelium-lined channels had occurred (Fig. 61d). Fibroblasts, inflammatory cells (mainly mononuclear and lymphocytic) and capillaries intervened between these channels and the internal elastic lamina. A considerable amount of blood pigment could be seen free and in scavenger cells. Only in one very small area was there fragmentation of the internal elastic lamina, and in one region it appeared to have been destroyed. The media was irregularly thickened and showed fibrosis and degeneration. Inflammatory cells of lymphocytic and mononuclear types were scattered through the outer coats. Most of the capillaries in the degenerated area appeared normal, but some had apparently been involved in a similar process (Fig. 61e). The lumen had been blocked and recanalized by one or two small endothelium-lined channels. Between these channels cells containing blood pigment could be seen.

The essential lesion appeared to be of the nature of thrombo-angiitis obliterans It is possible that the arteries in the right lower limb were similarly involved late in the course of the disease, but the elevation of temperature involved the whole of one side of the body.

Barron and Linenthal (1929) reported a number of cases upon which they based the conclusion that this disease attacked the entire vascular system. Cerebral vascular accidents occurred among their cases, but not as a solitary

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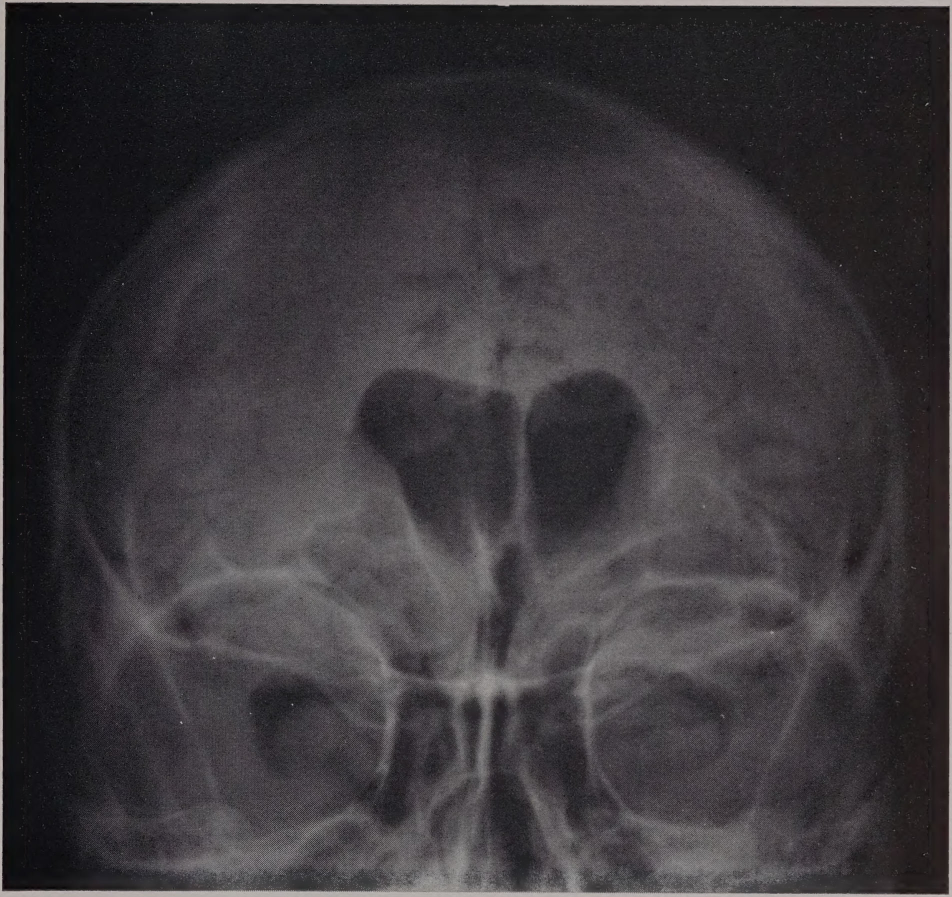

Fig. 61a—Antero-posterior skiagram in a patient with thrombo-angiitis obliterans.

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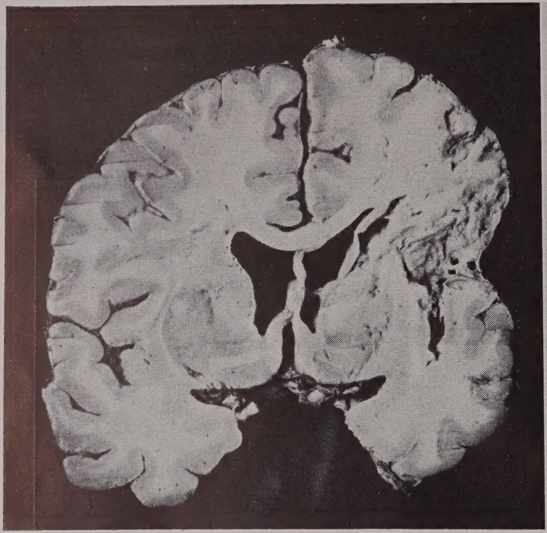

Fig. 61b—Coronal section in front of the interventricular foramen.

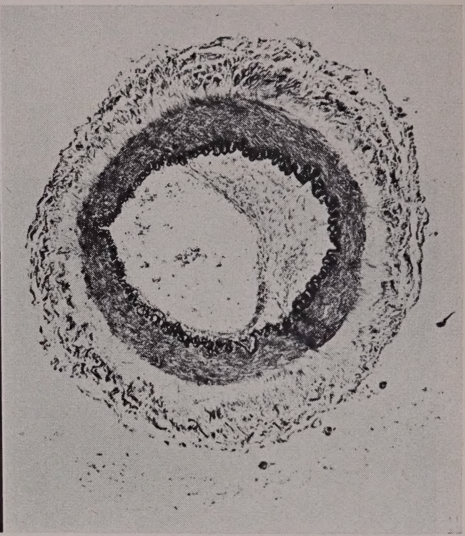

Fig. 61c—Artery from degenerated area.

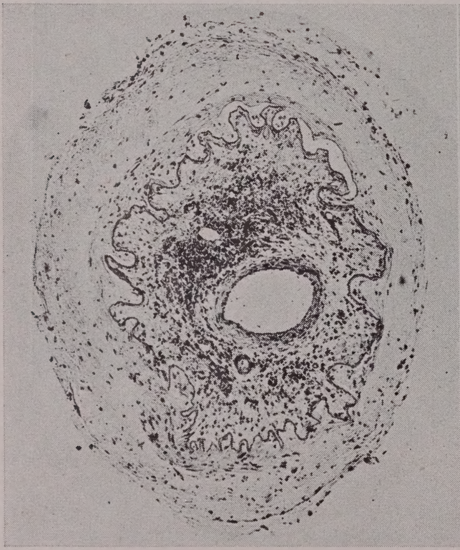

Fig. 61d—Branch of middle cerebral artery.

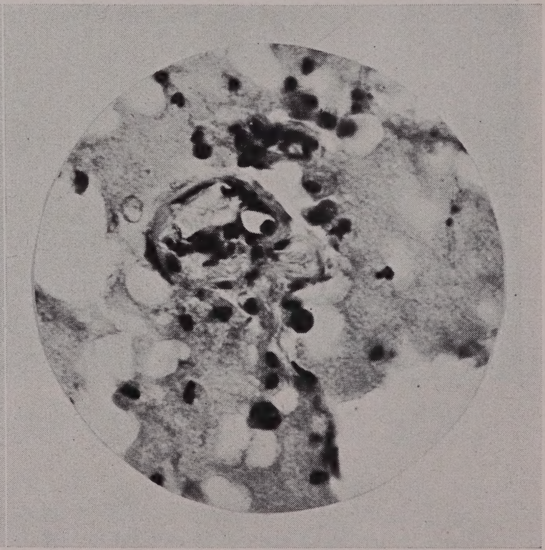

Fig. 61e—Capillary in the degenerated tissue.

feature. Probably in most cases the obvious lesions in the limbs draws attention to the diagnosis; and the cause is likely to escape recognition in cases with cerebral symptoms alone.

Inflammatory causes

Encephalitis is one of the most misused terms in diagnosis, and the correlation between clinical observation and pathological knowledge is far from complete. Probably some degenerative conditions have their origin in localized or diffuse inflammatory disease involving the brain or its vessels, although there may be little evidence of this inflammation at any stage. Some patients in the series had symptoms—usually headache, sometimes associated with epilepsy—of a relatively acute onset during the course of a staphylococcal infection of some part of the body. Physical signs were few, but the cerebrospinal fluid contained an excess of cells. In one, the lateral ventricle was 3 mm. larger on the side of a residual epileptic focus.

Symonds (1940), considering a number of similar cases, expressed the following view:

> It appears to me probable that cerebral thrombophlebitis by direct extension from an infective source or occurring as part of a generalized tendency to thrombophlebitis is not very uncommon and frequently runs a benign course. Such cases in the past may have been erroneously attributed to arterial thrombosis or embolism, or encephalitis. Some, especially those in which the onset has been with focal epileptic attacks, have doubtless been diagnosed as meningitis or abscess.

He believes that the sudden onset of focal symptoms—fits or paralysis—in a patient with otitis media may indicate an aseptic thrombophlebitis beginning in the lateral sinus and spreading to the cortical veins. With the establishment of a collateral circulation the symptoms may subside. An abscess may develop in the zone of cortical thrombophlebitis. If the pathway of spread has been along the superior longitudinal sinus blockage of absorption through the arachnoid villi may result in "otitic hydrocephalus." If the clot remains aseptic, organization and canalization restore the normal circulation, and the symptoms disappear. The ventricular picture in a patient with an acute cerebral complication of otitis media is of considerable interest in this regard.

S.L., a man of twenty-seven years, developed mumps, complicated by follicular tonsillitis and otitis media. His left ear commenced to discharge and he appeared to improve, but eleven days later he complained of headache and nausea, and became delirious. He was admitted to hospital three days later in a stuporose state. His temperature fluctuated between 99 and 101°F. There was slight cervical stiffness but no other neurological signs. The cerebrospinal fluid was under increased pressure and was clear and colourless. It contained 4 lymphocytes per c.mm. A Schwartz type of mastoidectomy was performed and the dura over the temporal lobe was exposed. It was bulging, yellowish-white, and did not pulsate. Thick yellow pus was aspirated from the subdural region. A cruciate incision was made in the dura and a small drain tube inserted. There was no escape of cerebrospinal fluid and only a small quantity of pus issued. On culture a profuse growth of haemolytic streptococci was obtained. Treatment was commenced with sulphapyridine orally and by injection. Three days later the cerebrospinal fluid was slightly turbid and its pressure was 90 mm., although next day it reached 230 mm. It contained many polymorphs and a few mononuclear cells. The patient was delirious and restless. Seven days later it was impossible to understand his speech. The wound was still discharging. Four days later the pressure of the cerebrospinal fluid was 150 mm. It contained 13 lymphocytes, 1 large mononuclear and

1 polymorph per c.mm. The protein amounted to 70 mg., and the sugar to 50 mg. per cent. Fourteen days later the fluid was normal and the mental state was lucid. There was a right-sided homonymous contraction of the visual fields, most marked in the upper quadrants. The right side of the face and the right hand were slightly weak. There was marked aphasia, chiefly of the nominal type, with difficulty in comprehending spoken and written speech and in the construction of sentences. The pressure of the cerebrospinal fluid on successive punctures was 190 mm., after three weeks; 70 mm., after thirty-one days; 220 mm., after fifty-two days; 180 mm., after sixty-two days. The fluid was normal.

He continued to improve. Two months later, there was still slight nominal aphasia. The visual fields had expanded slightly. The mastoid wound discharged small quantities of pus. Encephalography at this stage showed that the whole of the left temporal horn was dilated. The diameters of corresponding parts of the temporal horns were: right, 1 cm.; left, 1·7 cm. There was no displacement of the ventricular system. The body of the right ventricle was slightly larger than that of the left (right, 2·1 cm.; left, 1·9 cm.).

It was believed on clinical grounds that this patient had a suppurative encephalitis in the left temporal lobe, which had become localized with the formation of an encapsulated abscess. The finding of a dilated temporal horn was inconsistent with this diagnosis. Such uniform dilatation would hardly be produced by the contraction of an area after encephalitis. It is possible that localized inflammation led to involvement of the walls of temporal branches of the middle cerebral artery, with blockage of the artery and ischaemic necrosis of the substance of the temporal lobe. On the other hand, the atrophy of the temporal lobe may have been secondary to thrombophlebitis spreading via the inferior anastomotic vein, which runs from the lateral sinus to the superficial middle cerebral vein. In Symonds's cases the symptoms recorded were due to disease of the frontal and parietal lobes, but if the thrombophlebitis should spread by the pathway mentioned the temporal lobe might well be affected.

In another patient generalized convulsions and stupor followed the development of a discharge from the right ear. The cerebrospinal fluid was under a pressure of 200 mm. and contained 20 lymphocytes per c.mm. The patient gradually recovered. Encephalography six weeks after the onset revealed no abnormality. The patient continues to suffer from occasional sensory Jacksonian attacks.

In several patients dilated cerebral ventricles have been found in association with long-standing mastoiditis. In one, chronic mastoid disease was followed by the development of fits, and much later, of slight cerebral deterioration. Encephalography on two occasions, ten and eleven years after the commencement of the fits, revealed generally dilated ventricles and slight widening of the sulci. The measurements of the ventricles were: right, 2·2 cm.; left, 2·1 cm.; and, a year later: right, 2·4 cm.; left, 2·2 cm. In another patient with similar symptoms marked internal hydrocephalus was associated with obliteration of the subarachnoid pathways over the upper part of the convexity.

Many of these cases with degenerative lesions are examples of pathological processes not yet understood. It is even difficult to say whether some exemplify degenerative, vascular or inflammatory disease. Apparently there are all grades of severity of these processes, some leading to death, others terminating spontaneously, without producing much damage to the brain, although the abnormal areas may later act as foci for epileptic attacks. The initial cause of many of these degenerative conditions is at present obscure.

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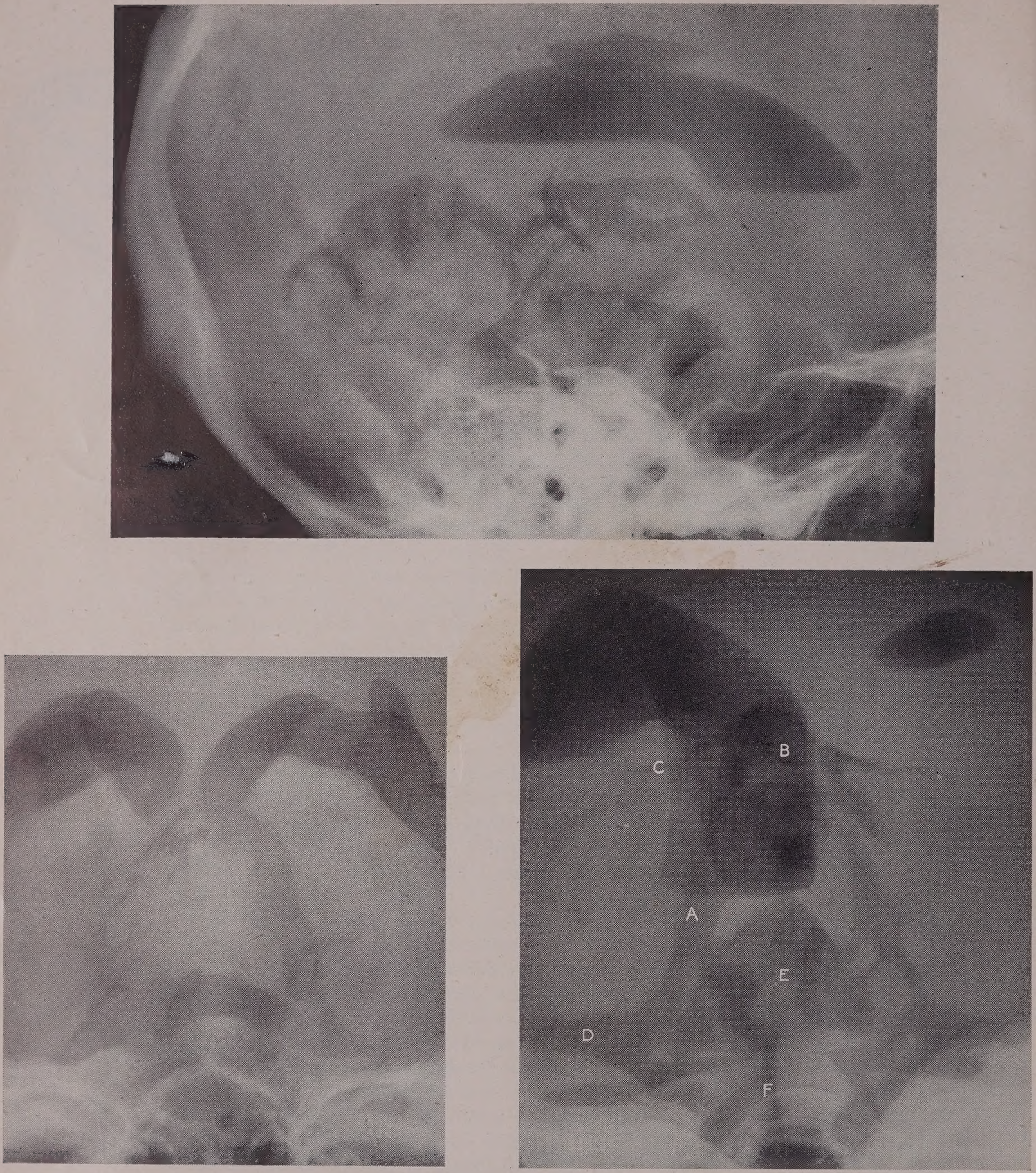

Fig. 62—To demonstrate the interpeduncular and ambient cisterns—(a) lateral view. From the cisterna venae magnae cerebri air extends posteriorly between the vermis and the tentorium; (b) recumbent postero-anterior view. Below, the interpeduncular cistern overlies and rises above the dorsum sellae. The two limbs of the ambient cistern are faintly outlined and converge in the cisterna venae magnae cerebri; (c) postero-anterior view during filling with neck flexed. A, ambient cistern. Below the letter A the ambient cistern turns medially into the interpeduncular cistern. B, cisterna venae magnae cerebri. C, air extending over superior surface of the cerebellum. D, air behind the posterior surface of petrous temporal bone and below the tentorium, i.e., in the lateral pontine cistern. E, fourth ventricle superimposed upon the shadow of the interpeduncular cistern. F, column of air rising to fourth ventricle.

To face page 93.

Chapter IX

AIR IN EXTRA-VENTRICULAR POSITIONS

Thus far attention has been directed mainly to the ventricles. As a corrective to this, it may be stated that important information is sometimes obtained by studying the X-ray shadows of air in the subarachnoid space. Suitable modifications of technique permit one to fill selected portions of this without the distress which may attend complete filling; or alternatively a general anaesthetic may be used.

The subarachnoid space

The subarachnoid space lies between the pia mater covering the cerebral structures and the arachnoid, which is closely applied to the smooth dura mater. It is bridged by filaments of arachnoid and is very irregular in width, forming cisterns in the widest parts (Fig. 7a). Stereoscopic skiagrams are particularly useful in recognizing the pattern of the cisterns and the cerebral sulci and gyri. As has already been shown, in the flexed position of the neck air first enters the cisterna magna, which has been described in detail in earlier pages. When the posterior part of the cistern is large it may be seen as a faint shadow in the original postero-anterior views (Fig. 17e). In these cases it usually extends to the inion and is of varying width. It is usually divided by the bony opacity of the internal occipital crest. The narrow vertical shadow thrown by air in the anterior part of the cistern may be seen in the mid-line at the lower end of the shadow. Its appearance precedes filling of the fourth ventricle. In lateral films the cistern is seen close to the occipital bone. Occasionally it is very extensive (Figs. 17d and 41), but usually it extends about 3 cm. behind the posterior lip of the foramen magnum (Figs. 20b and 22a). This area of the skull is normally radio-translucent and some difficulty may arise in distinguishing the cistern. The borders of the cisternal shadow are, however, well defined and the convex curve of the upper end of the cistern may be helpful in distinguishing ill-defined cases.

In the posterior fossa, air which does not enter the ventricles usually ascends in front of the medulla and pons. Occasionally, however, air escapes from the cisterna magna, through defects in the usual barrier between the cistern and the remainder of the subarachnoid space over the cerebellum (Fig. 21a, b). In such cases, the relative resistance opposed by the two pathways of escape from the cistern—the ventricular and the subarachnoid—determines the distribution of air. However, the partition between the cistern and the remainder of the subarachnoid space over the cerebellum is usually complete and it is then difficult to show the postero-inferior surface of the cerebellum with any certainty, even in extensive replacements. In the flexed position of the head, however, air may extend from the ambient cistern, posteriorly and slightly upwards under the tentorium (Fig. 62a) and thus the upper surface of the cerebellum is frequently outlined. The shadow is distinguished by the irregularity of its outlines. The lower border often appears as a series of irregular arches.

Air entering the skull in front of the medulla rises in the cisterna pontis (B, Fig. 7a) anterior to the pons. Key and Retzius have provided a detailed description of this cistern. It is limited above and below by fine perforated membranes of varying development, attached along the grooves between pons and medulla, and pons and mid-brain respectively. This space, so delimited, is divided into three compartments by vertical septa. Two are situated on each side of the basilar artery as it ascends along the median groove of the pons. Cranially and laterally, the arachnoid forming the anterior boundary of the lateral pontine cistern passes, on each side, over the cerebral peduncle to the temporal lobe, and at a lower level over the middle cerebellar peduncle on to the anterior surface of the cerebellum. The anterior part of the pontine cistern is seen in lateral films whenever air passes cranially anterior to the medulla and pons (Fig. 34c). The basilar artery runs cranially in the median cistern and may sometimes be seen in encephalograms. The lateral cisterns may be seen in infero-superior and inclined postero-anterior views, as will be described later. This region may be worthy of further study for the important fifth, sixth, seventh and eighth cranial nerves cross it, and the neoplasms in the cerebello-pontine angles are not uncommon.

From the pontine cistern the air enters the interpeduncular cistern (C, Fig. 7a), which extends between the cerebral peduncles to the posterior border of the infundibulum. Key and Retzius describe its division into superficial and deep cisterns by a thin membrane. In lateral encephalograms the cistern may be seen as a dark quadrangular accumulation of air (Fig. 63). Its posterior boundary is formed by the posterior perforated space, between the peduncles, and its anterior boundary by the infundibulum and the dorsum sellae below. The rounded inferior margins of the corpora mamillaria may be seen anterior to the peduncles (Fig. 34c). If the third ventricle is filled its floor can be seen (Fig. 63) separating the ventricle and cistern. The oculo-motor nerves, and the posterior cerebral and posterior communicating arteries are important contents of this cistern, but are rarely identified.

In front of this cistern is the cisterna chiasmatis (D, Fig. 7a; Fig. 63) situated anterior to the infundibulum and above the diaphragma sellae. The outline of the optic nerves may sometimes be seen passing forwards from the optic chiasma. Between the medial surfaces of the frontal lobes and anterior to the lamina terminalis is the cisterna laminae terminalis (E, Fig. 7a; Fig. 63). It extends upwards to the rostrum of the corpus callosum. The anterior cerebral arteries and the anterior communicating artery cross this cistern and have been seen very clearly in one encephalogram. From this cistern the cisterna fossae Sylvii extends laterally and the cisterna corporis callosi anteriorly. The cisternae fossae Sylvii extend laterally below the anterior perforated substance of the frontal lobes to the medial surface of the temporal lobes. The floor of each is formed by the arachnoid bridging between frontal and temporal lobes and each becomes continuous with the subarachnoid space in the Sylvian fissure. In antero-posterior skiagrams the cisterns are recognized as broad shadows just below the sphenoidal ridge.

The anterior cerebral arteries, extending forwards from the cistern of the lamina terminalis, follow the curve of the corpus callosum and run in a wide subarachnoid space which is called the cistern of the corpus callosum. The callosal sulcus extends laterally on each side from this. Both cistern and sulci are frequently seen in lateral and antero-posterior skiagrams.

The ambient cisterns (F and G, Fig. 7a) extend laterally around the cerebral peduncles and mid-brain with the medial part of the inferior surface

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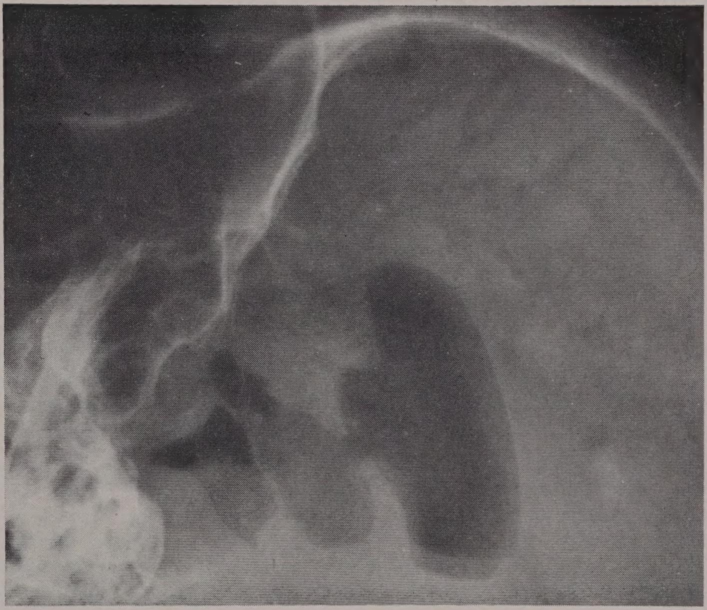

Fig. 63—Lateral skiagram, with brow up, showing the anterior part of the third ventricle and the cisterns intimately related to it.

To face page 94.

of the temporal lobe above, and the lateral pontine cistern below, with the cerebellum more posteriorly. Posteriorly the limbs of the cistern meet in the mid-line behind the quadrigeminal plate, where there is a wide expansion (G, Fig. 7a), which has been termed the cisterna venae magnae cerebri, since it is traversed by the great vein of Galen. The anterior wall of this cistern is formed by the pineal gland above, with the quadrigeminal plate and superior medullary velum below. Posteriorly it reaches to the cerebellum and is roofed by the inferior surfaces of the tentorium and the splenium of the corpus callosum. The ambient cisterns thus form a buffer between the mid-brain and the free edge of the tentorium, and into this space the uncus may be forced should the temporal lobe expand. Two, and sometimes three, cisterns open into the cistern of the great cerebral vein. Above is the posterior extremity of the cistern of the corpus callosum. Posteriorly, a space which is often wide, may be seen between the superior surface of the cerebellum and the inferior surface of the tentorium—the superior cerebellar cistern (Fig. 62a). A median part of the choroidal fissure may occasionally be seen extending anteriorly below the corpus callosum and fornix and above the roof of the third ventricle (H, Fig. 7a; Fig. 34c). This state is due to an early halt in the process of development. Normally the two layers of arachnoid, the lower of which is associated with the pia mater bearing the choroid plexus, are brought into contact between the developing corpus callosum and the roof of the third ventricle. Fusion usually occurs but occasionally the space persists in varying degree. Two thin columns of air may sometimes be seen curving over the dorsal surface of the pulvinaria of the thalami on each side under the posterior part of the corpus callosum. These are seen in figure 62a.

Air which has not passed into the ventricles will, in most cases, be seen in the ambient cisterns in the initial postero-anterior films. It is therefore important to recognize the appearance of air in the ambient cisterns in these films, for it may be possible to determine the entry of air into the ventricle by altering the conditions. Two faint irregular columns of air (Figs. 31 and 62c) are seen extending along lines drawn between the internal auditory meatus on each side and the position of the pineal gland—about 3·5 cm. above the posterior clinoid processes in radiograms taken in this posture. Thus the columns converge above, to meet in the cisterna venae magnae cerebri, where the air accumulates and casts a denser shadow with a characteristic rounded upper limit. This may be faintly seen in figure 34b. When the third ventricle contains air the suprapineal recess is seen below the cisterna venae magnae cerebri. When the ambient cisterns are well filled they appear to commence near the lateral ends of wider shadows which run along the medial parts of the petrous temporal bones (Figs 31 and 62c). Careful study of radiograms of the skull and models of the cisterns show that these shadows represent air over the posterior surfaces of the petrous temporal bone medial to the lateral lips of the internal auditory meati, that is to say, they represent the lateral recesses of the pontine cisterns. Apparently air is able to escape cranially from these lateral recesses, entering the anterior parts of the ambient cisterns. A study of the anatomical relationships shows that this is readily possible and in lateral films air is sometimes seen extending from the level of the petrous temporal bones to the ambient cisterns.

In lateral views the ambient cisterns appear as well-defined shadows which extend posteriorly, with a slight upward slope, from the interpeduncular cistern, finally to curve upwards before meeting in the cisterna venae magnae cerebri (Figs. 37, 62a and 65). The air in this cistern may clearly reveal its boundaries, the dorsal surface of the quadrigeminal bodies being most frequently outlined.

Attempts have been made to show the basal cisterns by taking infero-superior views. The patient sits with his back to the head-table, so that, when the head is fully dorsiflexed, the vertex will come into contact with the head-table. Using a horizontal ray, views of the base of the skull are taken before the introduction of air and during filling in this posture, or in the usual posture when the basal cisterns have been filled (Fig. 64). The shadow of air in the pharynx unfortunately destroys the clarity of delineation of the cisterns; indeed at first sight only an increased density of the shadow of the pharyngeal air may be apparent. It may prove difficult to define the boundaries of the cisterns, although when the filling has been completed the air can clearly be seen extending through the foramen magnum. Of the basal cisterns, the interpeduncular cistern usually throws the densest shadow. From the pontine cistern air may be seen extending laterally along the posterior surface of the temporal bones into the lateral recesses. This method is of little value.

The following procedure has proved most useful in defining the lateral recesses of the pontine cisterns. Ten c.cm. of air is introduced moderately rapidly in two equal quantities, with the patient's back and neck extended. His head is then flexed so that the eye-ear line makes an angle of 25° with the horizontal plane. Stereoscopic postero-anterior views are then taken. This method may prove useful in excluding a large lesion in the cerebello-pontine angle. Stenver's position has been used, but the density of the petrous temporal bone robs the method of much of its potential usefulness.

Cerebral sulci

From the cisterns the air tends to rise to attain the highest possible position. It does not extend over the whole subarachnoid region, but follows pathways which are apparently provided by a widening of the subarachnoid space around vessels in the sulci. The pattern of the sulci may thus be recognized. These are very fully described by Davidoff and Dyke (1937). On the lateral surface of the brain the central sulcus of Rolando extends downwards at an angle of sixty-seven degrees from a point half an inch behind the mid-point of a line joining the glabella and the inion (Fig. 48). In front, the precentral gyrus may be delimited by the often-broken line of the precentral sulcus. The superior and inferior frontal convolutions separating the superior, middle and inferior frontal gyri, are difficult to differentiate from the secondary convolutions in the frontal lobes.

Posterior to the central sulcus the post-central sulcus may define the post-central convolution. The other convolutions of the lateral surface of the parietal and occipital lobes are usually too indefinite to identify, although the interparietal sulcus may occasionally be seen. The stem of the lateral fissure of Sylvius between the frontal and temporal lobes is best seen in antero-posterior films, extending parallel with the lesser wing of the sphenoid. After reaching the lateral aspect of the convexity the fissure divides into short anterior horizontal and anterior ascending limbs, and a longer posterior limb. The posterior limb of the fissure may commonly be identified, running along part of the line which joins the zygomatic process of the frontal bone

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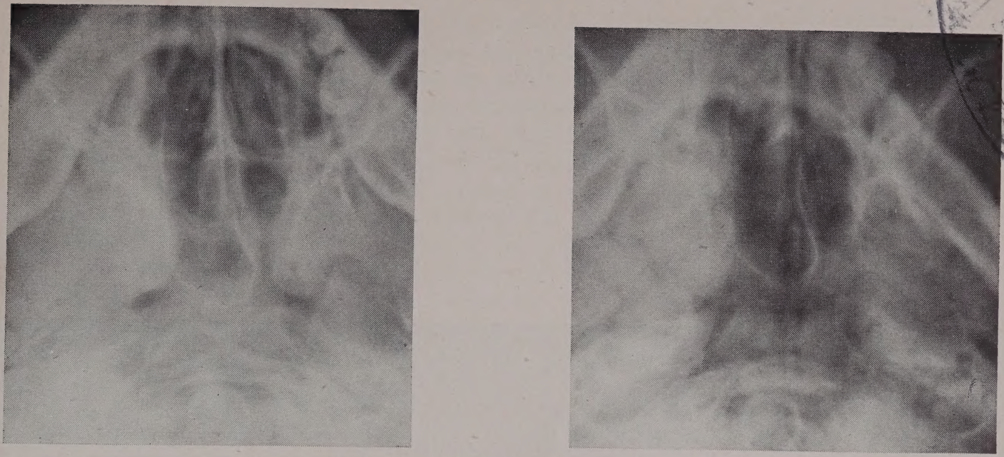

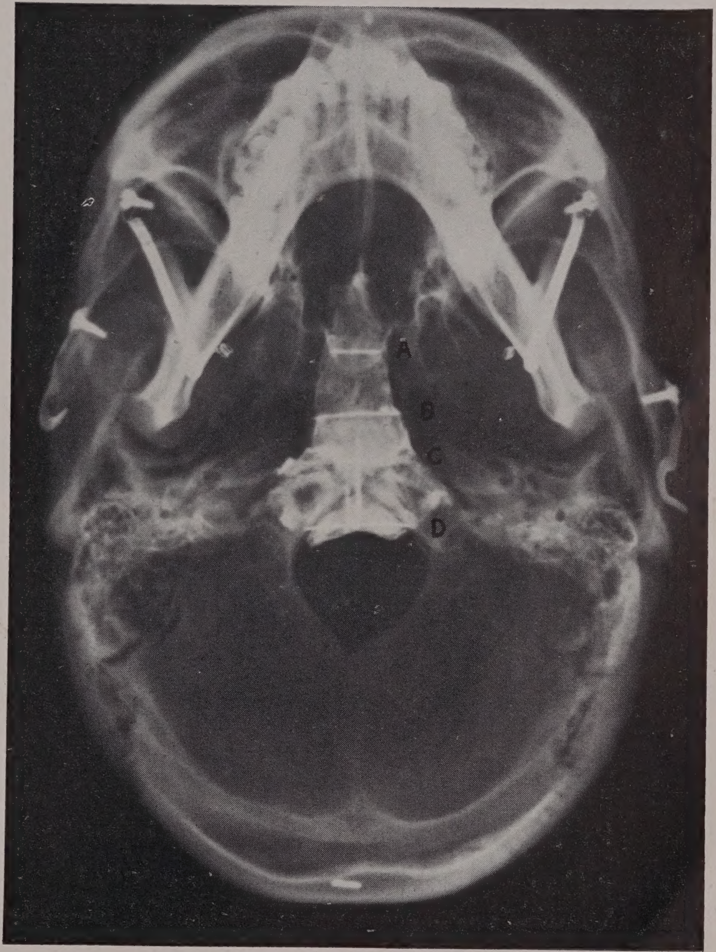

Fig. 64—To demonstrate filling of the basal cisterns seen in infero-superior skiagrams —(a) before the injection of air; (b) after the introduction of air. Apparently pharyngeal and cisternal shadows are superimposed. An extension of air into the left lateral recess is seen; (c) model of basal cisterns demonstrating their relations to the bones of the base of the skull. A, anterior extremity of interpeduncular cistern. B, junction of ventral parts of pontine and interpeduncular cisterns. C, level of postero-superior extremity of the interpeduncular cistern. D, inferior extremity of the pontine cistern.

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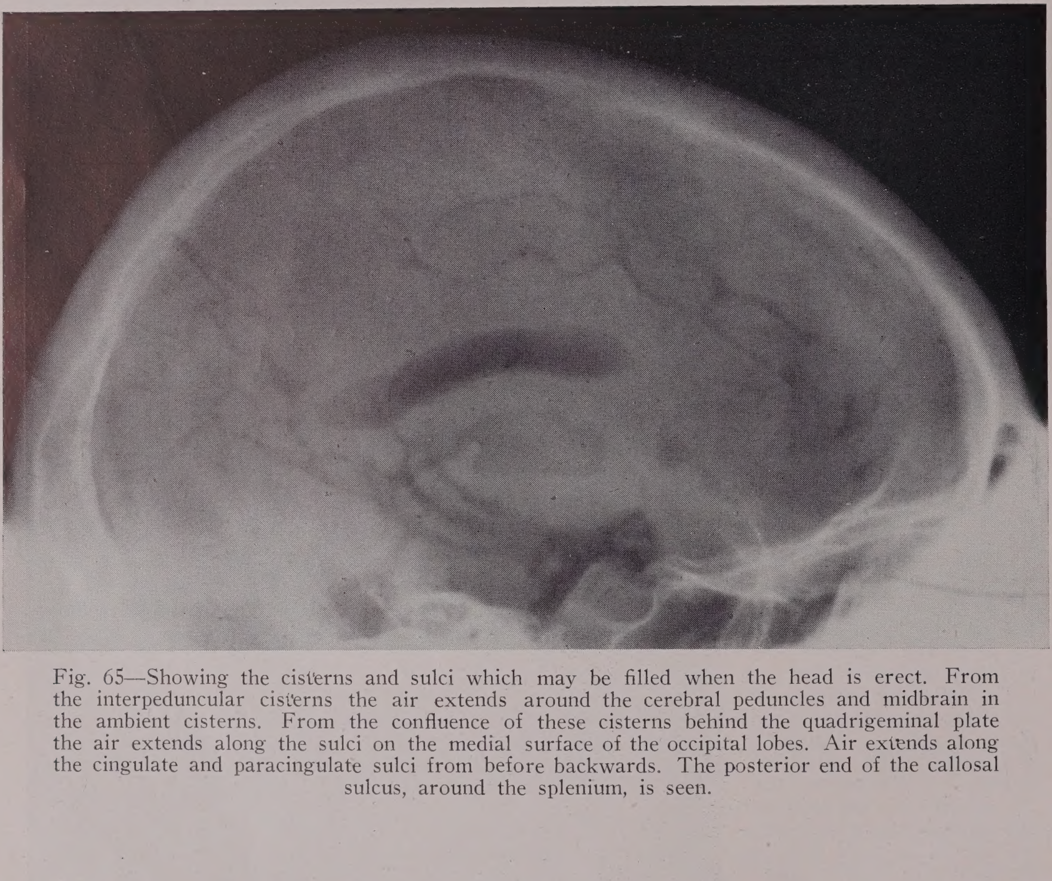

Fig. 65—Showing the cisterns and sulci which may be filled when the head is erect. From the interpeduncular cisterns the air extends around the cerebral peduncles and midbrain in the ambient cisterns. From the confluence of these cisterns behind the quadrigeminal plate the air extends along the sulci on the medial surface of the occipital lobes. Air extends along the cingulate and paracingulate sulci from before backwards. The posterior end of the callosal sulcus, around the splenium, is seen.

with a three-quarter point between the glabella and the inion (Figs. 48 and 66). The Sylvian point is situated on this line above the tuberculum sellae. About 4 cm. posterior to the point at which the line of the central sulcus meets the line of the posterior limb of the lateral fissure, the latter turns abruptly upwards to be capped by the supramarginal gyrus. Deep to the Sylvian fissure air sometimes outlines the island of Reil (Fig. 13b). The superior temporal sulcus, with its posterior upturned end capped by the angular gyrus, is commonly seen. The middle sulcus is less frequently seen. The gyri on the infero-medial surface of the temporal lobe have not been seen.

The large gyri on the medial surface of hemispheres are very constant in form, and are the gyri most frequently seen in encephalograms. The callosal cistern and sulci above the corpus callosum have been described. Below the rostrum of the corpus callosum the posterior parolfactory sulcus represents the downward continuation of the callosal sulcus in front of the subcallosal gyrus. Davidoff and Dyke (1937) have shown its importance in the recognition of a meningioma of the olfactory groove. Above the callosal sulcus the cingulate sulcus may be seen (Fig. 65). Between these sulci is the cingulate gyrus. The posterior end of the cingulate sulcus turns upwards and separates the paracentral lobule in front from the precuneus behind. The callosal and cingulate sulci may be seen in antero-posterior views, in which also the great longitudinal fissure may be delineated by a column of air between one hemisphere and the neighbouring surface of the falx (Fig. 49b). Air not uncommonly outlines this fissure and may provide important diagnostic information. The parieto-occipital fissure, separating the precuneus of the parietal lobe from the cuneus of the occipital lobe, extends downwards and forwards to meet the calcarine fissure about 2 cm. posterior to the splenium of the corpus callosum (Fig. 65). The calcarine fissure extends forwards and upwards from the region of the inion, and then turns downwards while continuing its forward course, to end beneath the splenium of the corpus callosum. The subarachnoid space within the fissure here enters the cisterna venae magnae cerebri.

Filling of selected spaces

It will be readily understood that air tends to follow three main pathways as it rises from the basal cisterns. By suitably posing the patient, air may be made to follow one or other of these routes:

(i) When the head is flexed the air passes from the interpeduncular cisterns around the cerebral peduncles and the mid-brain in the ambient cistern of each side (F, Fig. 7a). These cisterns join posteriorly and from their confluence (the cisterna venae magnae cerebri, G, Fig. 7a) the air is able to rise around the splenium of the corpus callosum for a short distance, but chiefly along the calcarine and parieto-occipital fissures (Fig. 65). In the usual investigation air passes in this direction when it is not entering the ventricular system (as, for example, when the ventricles have already accepted as much air as possible).

(ii) When the patient is erect, with head and neck dorsiflexed (Fig. 18d), air passes forwards from the interpeduncular cistern into the cisterna chiasmatis, and then upwards between the frontal lobes (in the cisterna laminae terminalis, E, Fig. 7a) and along the cistern of the corpus callosum and the callosal and cingulate sulci. When the head is erect, without either flexion or extension, both these pathways may be followed (Fig. 65).

(iii) From the cistern of the lamina terminalis the air may travel outwards in the cisterna fossae Sylvii (Fig. 66), on each side, between the orbital surface of the frontal lobe and the temporal pole. From the lateral extremity of this cistern the air follows the sulci over the frontal and parietal lobes, along the course of the main stream of cerebrospinal fluid towards the longitudinal sinus. These sulci can be filled selectively by placing the patient in the inclined lateral position.

In the case illustrated in figure 66, there was widening of the cerebral sulci and dilatation of the ventricles, the latter apparently produced by obstruction to the absorption of cerebrospinal fluid. Air passed upwards in the enlarged sulci only to the horizontal level of the lateral ventricle, the subarachnoid space above this level being apparently obliterated. The patient had become increasingly demented over a period of ten years. Understanding of the significance of all stimuli appeared to be greatly reduced, speech was reduced to jargon and the limbs showed tonic innervation and reflex grasping. There was a history of otorrhoea for some years before the slow onset of the mental deterioration. This patient died thirty-six hours after encephalography which was performed under avertin anaesthesia. Post-mortem examination revealed general dilatation of the ventricles with atrophy of the convolutions. The pia-arachnoid over the vertex of the brain was thickened and the subarachnoid space in the widened sulci was obliterated.

An analysis of lateral skiagrams taken during a moderately complete replacement will serve to recapitulate some of the points mentioned. One hundred and forty c.cm. of air were introduced while 130 c.cm. of fluid were evacuated over a period of thirty-five minutes. The patient spoke somewhat irritably of a headache towards the end of the procedure, but his colour and pulse remained good and he did not vomit.

After 15 c.cm. had been introduced air was seen in the cisterna magna, extending from its upper limit to the level of the foramen magnum, and in each of the ventricles. The shadow of the fourth ventricle and aqueduct were very faint. When 30 c.cm. had been injected the shadow in the cisterna magna extended down to a horizontal level between the foramen magnum and the arch of the atlas. The amount of air in one lateral ventricle had greatly increased and the shadows of the median ventricles were more definite. Air was seen in the pontine, interpeduncular and ambient cisterns. From the confluence of the latter (the cisterna venae magnae cerebri) air outlined a small part of the upper surface of the cerebellum below the tentorium. After a further 10 c.cm. had been introduced the air in the cisterna magna extended down as far as the arch of the atlas. A faint column could be seen in front of the spinal cord. The chiasmal cistern was now evident. When 55 c.cm. had been introduced a shadow around the spinal cord extended to the level of the middle of the arch of the axis. At the upper border of the arch the shadow appeared to bifurcate. Most of the air passed posteriorly to the cisterna magna, but a well-defined shadow 3 mm. wide was seen in front of the spinal cord. From the cisterna venae magnae cerebri the air now outlined the dorsal surface of the splenium of the corpus callosum, and the sulci on the medial surface of the occipital lobes.

After a further 25 c.cm. had been injected the air filled the pre-central, central, post-central and other sulci over the parietal lobes, having reached these from the Sylvian fissure, which could be faintly discerned. When 100 c.cm. had been introduced this route was more definitely visible, and the

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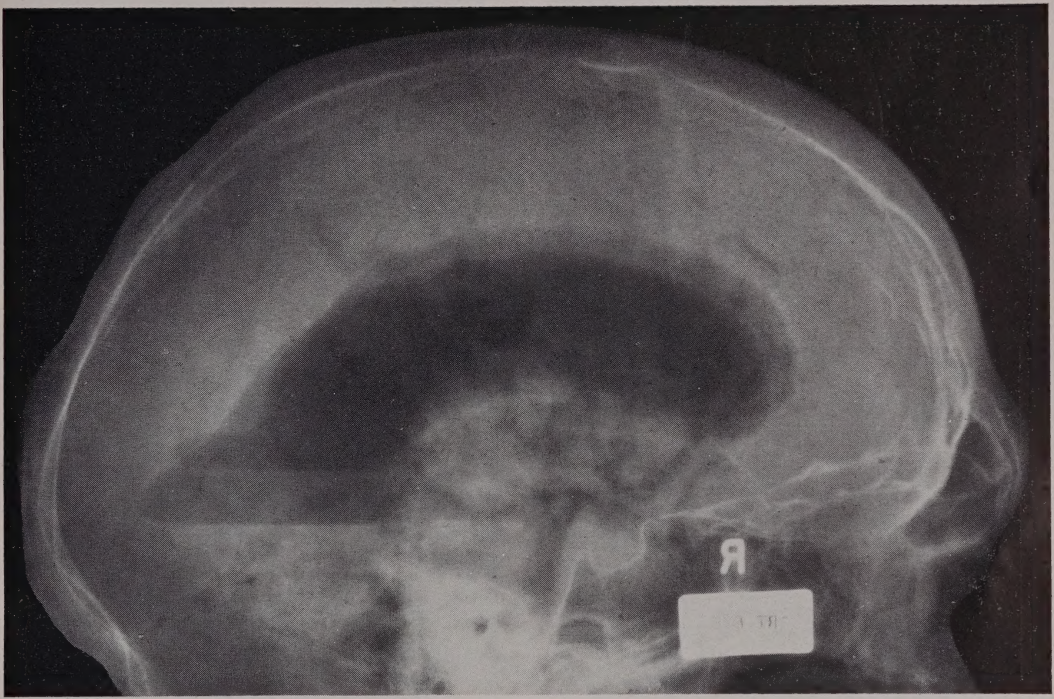

Fig. 66—Lateral skiagram with the head erect after an extensive replacement. The ventricles and lower parts of the sulci over the convexity are dilated owing to blockage of the subarachnoid channels over the upper parts of the cerebral hemispheres.

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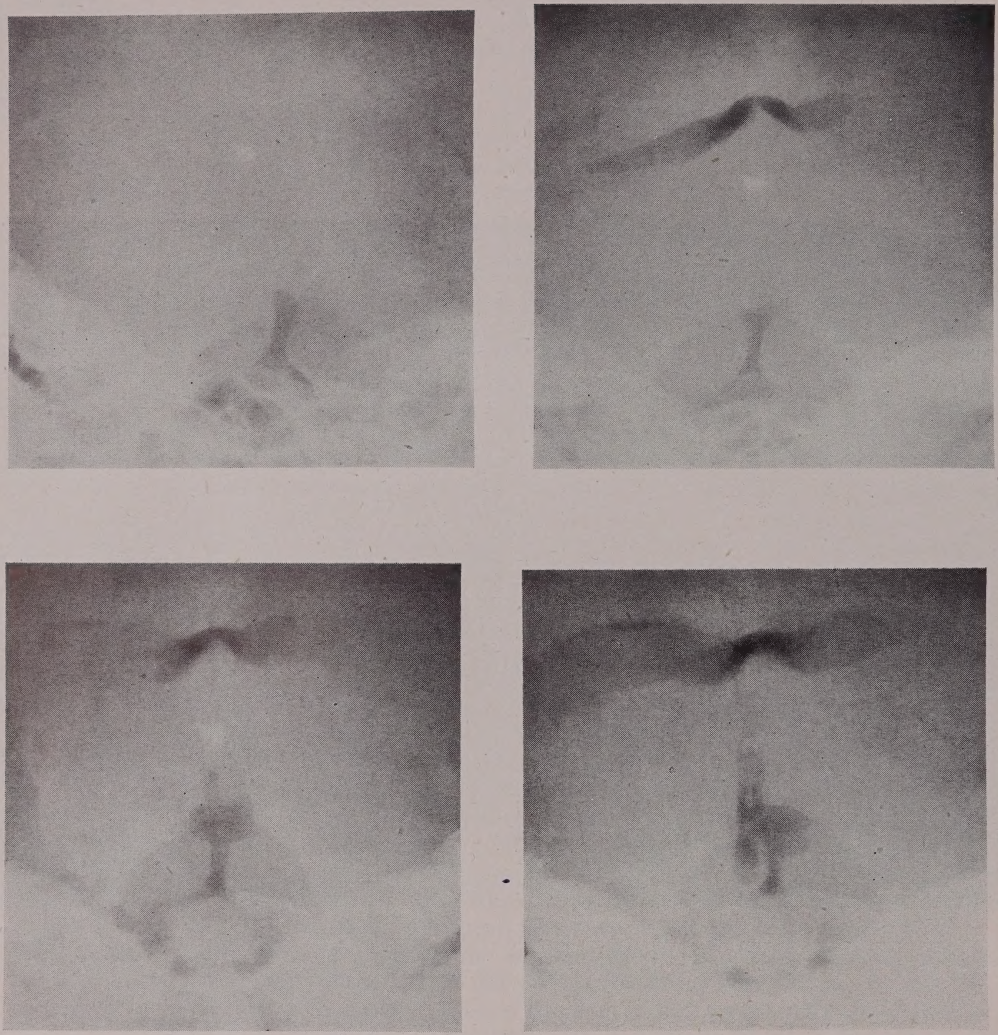

Fig. 67—To demonstrate the early appearance of air in the subdural space—(a) after injection of 5 c.cm. a column of air is seen in the region of the foramen magnum; (b) after 10 c.cm. have been injected air is accumulating under the tentorium; (c) after insertion of the needle into the subarachnoid space 5 c.cm. is injected and the fourth ventricle is filled; (d) two minutes later air has reached the third ventricle. The flexion of the head is greater than usual and the shadow of the third ventricle is projected to a low level (see figure 28). Slight rotation of the skull accounts for the apparent displacement of the third ventricle.

To face page 99.

sulci were more clearly defined. The shadow of the right lateral ventricle still continued to increase very slightly in length. The amount of air in the left ventricle had not increased beyond that seen after 30 c.cm. had been introduced. When 140 c.cm. had been introduced the shadow of air around the spinal cord extended to the arch of the fifth cervical vertebra. Another film was taken three minutes later, without the introduction of further air. Air now extended around the genu of the corpus callosum in the callosal and cingulate sulci. The superior surface of the cerebellum and the cerebral sulci (which were slightly dilated) were more clearly defined. When the head was placed in the erect posture the air within the spinal column extended to the level of the arch of the axis.

The subdural space

Air which enters the subdural space in the posterior fossa is recognized in the postero-anterior skiagram as a dense shadow corresponding with the curve of the tentorium, under which it accumulates. In lateral films the layer of air is seen to extend forwards and upwards to the region of the incisura tentorii, through which it passes slowly to attain higher levels. The edges of the shadow are smooth, and lack the characteristic irregularity communicated to subarachnoid air by the folia of the cerebellum (Fig. 62). In three cases where air was seen to be in the subdural space in the first film, the needle was withdrawn. In two of the patients it was re-introduced in a higher space, in the third it was inserted more deeply. The ventricles were then filled. Figure 31 shows air in the fourth ventricle in one of these cases.

A detailed analysis of another case provides evidence that air may be recognized in the subdural position before it is seen accumulating under the tentorium. The needle was inserted between the third and fourth lumbar vertebrae. The cerebrospinal fluid ascended in the manometer only to the level of the third thoracic vertebra, an unusually low level. The film (Fig. 67a) taken immediately after the introduction of 5 c.cm. of air showed a small column of air ascending through the foramen magnum. The shadow did not appear to differ in position from that usually seen rising to the fourth ventricle but it was noticed that the shadow of the superficial part of the cisterna magna (which is not constantly seen in postero-anterior views) was absent. The next film (Fig. 67b) taken immediately after the introduction of 10 c.cm. of air showed that the shadow was an unusual one. It was wide below and the lateral margins curved smoothly to a narrow waist and expanded again at the upper level of the foramen magnum. It was not surmounted by the rounded shadow of the fourth ventricle. By this time air had accumulated under the tentorium and was throwing the characteristic shadow of air in the subdural space. Evacuation of fluid was quite free, suggesting that some part of the bevel of the needle was in the subarachnoid space, or at least had originally pierced it, leaving a hole through which fluid could freely enter the subdural space. The needle was then withdrawn and reinserted into the space between the fourth and fifth lumbar vertebrae. The fluid rose to the same height in the manometer as at the previous puncture. Immediately after 5 c.cm. of air had been injected it was seen to be in the fourth ventricle and in the aqueduct of Sylvius (Fig. 67c). The quantity of subtentorial air had increased, as the result of the previous injection. Two minutes later air was seen in the third ventricle (Fig. 67d) and five minutes later it had accumulated in the lateral ventricles.

It is possible to trace the intracranial course of air in the subdural space in a series of radiograms. In lateral views the air is seen to enter the skull through the posterior part of the foramen magnum (Fig. 68a). The shadow then turns abruptly backwards to cover the medial part of the occipital bone. At the internal occipital protuberance it turns forwards and eventually forms a dense triangular shadow, with its acute angle posteriorly and its short base anteriorly, reflecting the tent-like arrangement of the tentorium. In postero-anterior views, with the head flexed, a well-defined vertical band of air some 5 mm. in width is seen in the mid-line of the posterior fossa (Fig. 68b). This shadow fans out shortly before reaching the inion. The air then passes forwards towards the incisura tentorii. There is apparently some resistance to its further passage, for the air commences to accumulate at this point, while the shadow gradually extends to outline the under-surface of the tentorium. The peak of the tentorium, which is related to the cisterna venae magnae cerebri, is well seen in such views. When the head is erect the air next ascends on each side of the falx cerebri (Fig. 68c). Near the vertex the two columns diverge to embrace the longitudinal sinus, on each side of which the air extends over the arachnoid of the cerebral hemispheres. The subdural space apparently allows rapid transit of air, except through the incisura tentorii. In each film taken in recumbency the air occupied the highest available position. Over the cortex the subdural air appears as an uninterrupted layer, with a smooth inner surface (Fig. 68c).

Thus, in the subdural space, as well as in the subarachnoid space, the course of the air is determined by the fact that it rises by the shortest route to the highest point available.

There has been some discussion as to the route by which the air reaches the subdural position. Stone and Jones (1933) have shown in post-mortem studies that air injected into the spinal subdural space may collect over the cortex beneath the dura. They suggest also that stretching of the arachnoid at the points at which the arachnoid granulations pierce the dura may allow the escape of subarachnoid air into the subdural space. This, they surmise, may be produced in life by the shift of the brain which results during encephalography when the patient's head is on one side. Penfield (1937) has shown that, if the region of a meningo-cerebral cicatrix is kept uppermost in post-traumatic cases, air will pass gradually from the subarachnoid space into the subdural space. The alteration of the distribution of air by movement of the point of the needle, and the tracing of air from the foramen magnum to the vertex, affords further evidence that the air may be introduced directly into the subdural space at the site of the puncture. Indeed, this is considered to be the usual cause. In considering the diagnosis in cases in which a localized collection of air appears over the vertex, it is important to know that air has not been seen in the subdural position under the tentorium; for in that event it will normally rise over the vertex and accumulate alongside the falx.

A deliberate initial puncture with a sharp short-bevelled needle probably lowers the percentage of cases in which subdural air appears. The running commentary provided by early films, taken during the slow introduction of air, allows the recognition and rectification of a mistake in technique. A long bevel may be coincidently in the subdural and subarachnoid spaces and it may then introduce air into the former and evacuate fluid from the latter. In some cases the air rises coincidently in both spaces. Hence a change in the position of the point may secure the desired result. More usually, how-

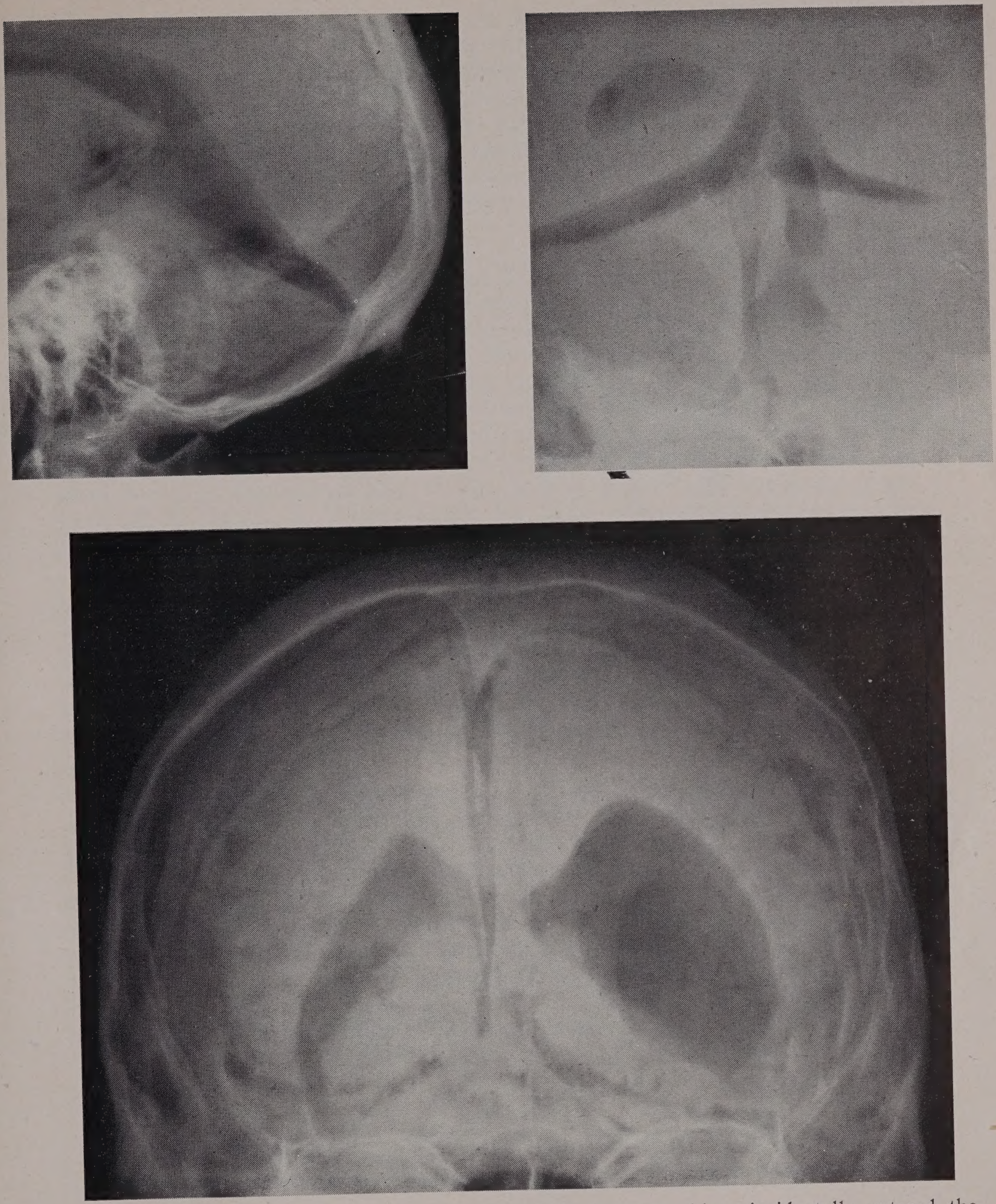

Fig. 68—To illustrate the course of air in the subdural space. Air coincidentally entered the ventricles—(a) lateral view showing air rising through the foramen magnum and extending along the occipital bone to the inferior surface of the tentorium; (b) postero-anterior view. In addition to the usual shadows of the fourth and third ventricles, a narrow column is seen in the mid-line, supplying the accumulation under the tentorium; (c) postero-anterior view showing air on each side of the falx and superior longitudinal sinus, and over the convexity of each hemisphere. During filling the shadow is usually dense enough to be seen only alongside the sinus and the upper part of the falx.

To face page 100.

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ever, the point, which was originally in the subarachnoid space, has slipped into the subdural space. It is better to withdraw the needle and introduce it into another intervertebral space. This may not always be successful, especially if a coarse needle has produced a wide opening in the arachnoid at the first puncture, allowing escape of fluid into the subdural space. This relaxes the tension of the arachnoid so that the needle pushes it ahead and remains in continuity with the subdural space, from which fluid will escape. As has been mentioned, it may then be necessary to resort to cisternal puncture.

Epidural injection

It is possible to introduce air into the epidural region. Fluid may drip from the needle, but its pressure is very low. It is unlikely that the bevel would be in both the subarachnoid and epidural spaces at the same time, so it seems probable that the fluid escapes from the spinal theca through tears in the arachnoid and dura produced by the needle. The air introduced is re-expelled forcibly when the syringe is removed showing that the air becomes loculated, and does not ascend around the dura. Even if air were injected into the epidural space just below the foramen magnum it cannot enter the skull owing to the arrangement of the dura at the foramen magnum. I am indebted to Dr. R. J. Wright-Smith for the following description of this anatomical disposition:

> In the skull, the inner and outer layers of the dura mater are firmly fused and cannot be separated. At the foramen magnum the outer layer is firmly attached to the bone. The inner layer passes through into the spinal canal. In the spinal canal below the atlas, the dura mater is completely free from the bony wall. In the region of the atlas, however, it appears to split. The outer layer extends upwards to fuse with the periosteum on the outside of the skull bones, while the inner layer passes upwards into the skull cavity. The outer portion of the inner layer is very firmly fixed to the bone at the foramen magnum.

It is interesting to reflect that this slightly complicated arrangement is almost demanded by the difficulties of the situation, which calls for a strong, flexible and water-tight connection between cranial and spinal cavities.

Air has been introduced between these layers accidentally during cisternal puncture. As seen in lateral views the air accumulated in a triangular shadow. The posterior limit extended from the anterior edge of the posterior part of the arch of the atlas, upwards and backwards to a point on the occipital bone about half an inch posterior to the foramen magnum. Thence the shadow extended downwards and forwards below the occipital bone. The anterior limit was rather difficult to define.

Chapter X

THE VALUE OF ENCEPHALOGRAPHY

The value of encephalography lies in the fact that it is a useful auxiliary in accurate diagnosis. It affords a practical means of distinguishing between lesions capable of extirpation, and those of which this is impossible. Successful treatment by surgical means is possible in the first group; in the second group medical treatment alone is possible.

There are limitations to the use of encephalography in the diagnosis of neoplasms. If the intracranial pressure is known, or suspected, to be raised, the method is best avoided, owing to the danger of increasing incisural or foraminal herniation. But the peculiar value of encephalography lies in the fact that it is a relatively simple method of establishing with certainty the presence of a neoplasm, when the absence of signs and symptoms of raised intracranial pressure leave the clinical picture incomplete. In most such cases it serves only to confirm the clinical diagnosis. It has always to be remembered that a normal encephalogram does not actually exclude the presence of a neoplasm, nevertheless such a finding is often of value in making an alternative pathological diagnosis more tenable. In some cases, the suspicion of the presence of a neoplasm may be so great that, in spite of a negative encephalogram, surgical exploration is undertaken. In any case, a normal encephalogram should not lead to relaxation of vigilance. In contrast, it is pertinent to remark that, in two patients examined during the period covered by this series, the diagnosis of neoplasm might have been made much earlier but for the reluctance of the patient to submit to investigation. Gliomata were present in both cases, and it is doubtful whether the patient suffered from the delay in operation. The evacuation of a subdural haematoma or the removal of scar tissue or of a meningioma will compensate for the much greater number of cases in which the nature of the lesion frustrates useful treatment.

The value of encephalography in the diagnosis of post-traumatic headache and epilepsy has probably been overestimated. In the latter case, an abnormal encephalogram is usually made the basis of a decision to operate, but normal ventricles may be present in cases of post-traumatic epilepsy. The recognition of small scars will depend upon more delicate methods of diagnosis. Whether surgery will play a valuable part in the removal of such small lesions is difficult to forecast.

Encephalography gives considerable help in the recognition of degenerative lesions. Thus it may provide the means of avoiding operative exploration and assists in deciding upon the proper management of the case.

As the method described provides excellent pictures of the fourth ventricle and the aqueduct of Sylvius it is of value in the diagnosis of pathological lesions in the posterior fossa. It provides a means of distinguishing between neoplasms and cerebellar degenerative lesions, and normal shadows may support the presence of vascular or inflammatory lesions. Experience is yet insufficient, but it may be surmised that early lesions may, in some cases, escape recognition.

Careful technique allows the filling of the ventricles alone in a high percentage of cases, and skiagrams of selected parts of the spaces normally filled with cerebrospinal fluid can be obtained with some certainty. The correlated study of the ventricles and the subarachnoid space will be necessary to obtain full information in some cases.

The problem of early diagnosis is complicated by the fact that small abnormalities may have no serious significance. It may be difficult to decide whether asymmetry of the ventricles is normal or abnormal. Encephalography is not a delicate method of diagnosis and, although very useful in some cases, it may yield information upon which an incorrect interpretation may be based. This position is largely corrected by experience and a knowledge of some of the established fallacies. Air studies furnish very accurate anatomical information, but this is not necessarily an accurate indication of pathological states. It might therefore seem that a close analysis of the findings in encephalography reduces the apparent usefulness of the method. Certainly, as experience increases the number of cases subjected to the procedure diminishes. In children the method rarely provides the basis for any alteration or improvement of treatment.

In the course of a series of investigations some patients gain greatly, and a number of unusual findings may emerge. By stimulating interest in the latter conditions during life, and by adding a background to the ultimate pathological investigation, encephalography may result in a valuable extension of neurological knowledge.

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